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ADVANCED RECEIVER MODELING METHODS

MCDONNELL AIRCRAFT COMPANY

MCDONNELL DOUGLAS CORPORATION

AIR FORCE AVIONICS LABORATORY

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Air Force Avionics Laboratory

Air Force Systems Command

Wright-Patterson Air Force Base, Ohio

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program develops an advanced methodology to aid the design, test and evaluation of receiver systems. Computer programs were developed for treating receiver performance degradations due to noise, nonlinearities, linear distortion, and signal interference. Specifically, two computer programs were generated for treating receiver processes encountered in signal paths and synthesizers respectively.

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Signal path computations are made relative to the receiver frequency plan, receiver noise figure and sensitivity performance, second and third order receiver intermodulation intercepts, permissible two sinusoid signal levels and dynamic range performance. Spurious response performance is computed for each spur product type generated at each mixer, yielding the worst case spur frequency and spur signal level at the receiver input and the corresponding worst case set of mixer local oscillator frequencies. Computations are also made of the receiver output waveform response to an essentially arbitrary input signal waveform.

Synthesizer program computations are made of the frequency plan, worst case phase modulation of each synthesizer output by spurious products generated at each phase comparator and mixer and worst case phase modulation of each synthesizer output by noise generated on each VCO and in the phase locked loop circuits. The synthesizer acquisition characteristic is also computed, determining the time to achieve frequency and phase lock at each synthesizer output.

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INTRODUCTION

1.1 PROGRAM SCOPE

The Advanced Receiver Modeling Methods (ARMM) program is addressed to the problems encountered by the Aerospace Systems Engineer concerned with systems that include radio receivers. The program applies the capability of the high speed digital computer to system engineering tasks, related to receivers, so that they may be carried out with greater accuracy, completeness and flexibility, at higher speed and with less effort.

In considering the application of the computer to the computation of receiver performance it is observed that computations may be made of overall performance, its variation with environmental changes, module performance, module component performance, worst case variation of module performance due to component variations, component tracking performance, the gamut of component, module and overall reliability predictions as well as the fine grain internal design parameters of components. It is apparent that some of these computations involve knowledge of design parameters not readily available to the systems engineer nor easily measureable by him.

To bound the scope of the program, an analysis is made of the tasks undertaken by the systems engineer relative to the performance parameters he requires and can measure or that otherwise are available to him. The Advanced Receiver Modeling Methods (ARMM) program is limited to computations of such performance parameters.

A second limitation to the scope of the program is the arbitrary exclusion of computations, such as reliability and temperature rise prediction, that are generally applicable to other types of equipment as well as receivers. Such computations may be effected by existing computer programs.

The term "receiver" as used in the program is taken in the broad sense as a device, fed by a modulated r.f. signal that recovers the modulation. The term "recover" may refer to: determination, with suitable probability, of the presence or absence of the signal; estimation, with suitable accuracy, of modulation parameters; determination of received data messages with an acceptable data error rate; or determination of the modulation waveform. The only exception taken to the above definition serves to broaden it: a receiver may also accept an unmodulated signal and estimate relative parameters. This definition is broad enough to encompass all accepted forms of receivers from the devices used by Hertz and Marconi in their basic experiments to Laser communications receivers.

With receivers broadly defined, the scope of the program is limited to those performance parameters which may be computed from a restricted library of functional module types. The preponderence of accepted receiver types may be modeled from the library of generic module types as employed by the computer programs developed under the ARMM program.

1.2 KEY RELATIONS USED IN COMPUTER PROGRAMS

SIGNAL PATH PROGRAM

<u>Cumulative Noise Figure</u>

$$F_T = F_1 + (F_2 - 1)/G_1$$

<u>Sensitivity</u>

$$P_S = (P_o/P_N)\ F_T\ KT\ B_N$$

where: F_1, F_2 = Noise Figures, Blocks 1, 2

G_1 = Gain Block 1

P_o/P_N = Output Signal/Noise Power Ratio

K = Boltzmann's Constant

T = Ambient Temperature (Degrees Kelvin)

B_N = Noise Bandwidth

<u>*Third Order Intermodulation Intercept (Cumulative)*</u>

$$P_{3T}^{-1} = P_{31}^{-1} + P_{32}^{-1} \cdot G_1$$

<u>Third Order Intermodulation</u>

Two Sinusoidal Signal Level to Yield Intermodulation Equal to P_N

$$P_3 = P_N + (2/3)\ P_{3T} \quad \text{(All Quantities Expressed in dbm)}$$

<u>Second Order Intermodulation Intercept (Cumulative)</u>

$$P_{2T}^{-1} = P_{21}^{-1} + P_{22}^{-1} \cdot G_1$$

<u>Second Order Intermodulation</u>

Signal Level Yielding Intermod Equal to P_N

$$P_2 = P_N + (1/2)\ P_{2T} \quad \text{(All Quantities Expressed in dbm)}$$

where: P_{31}, P_{32} = Third Order Intermod Intercepts, Blocks 1, 2

P_{21}, P_{22} = Second Order Intermod Intercepts, Blocks 1, 2

Spurious Response Performance (Spur Type j,k)

Spur Bands ω_1 to ω_2 ; ω_3 to ω_4

$$\omega_1 = (K\ \omega_{oL} - \omega_{IH})/j$$

$$\omega_2 = (K\ \omega_{oL} - \omega_{IL})/j$$

$$\omega_3 = (K\ \omega_{oH} - \omega_{IL})/j$$

$$\omega_4 = (K\ \omega_{oH} - \omega_{IH})/j$$

Spur Signal Level at Receiver Input to Provide Spur Response Equal to P_N

$$X = [(j-1)\ (P_{j,k} - G) + P_N]/j$$

(All Quantities in DB's; no Filtering Considered)

Spur Intercept

$$P_{j,k} = P_a + R_{j,k}/(j-1)$$

where: ω_{oL}, ω_{oH} = Minimum, Maximum Oscillator Frequency

ω_{IL}, ω_{IH} = Minimum, Maximum Mixer Output Frequency

G = Cumulative Gain Prior to Mixer

P_a = Input Signal Power to Mixer

$R_{j,k}$ = Mixer Output Signal/Spur Power Ratio

Waveform Performance:

Define: $a(t)$ = Input Signal

$b(t)$ = Output Signal

$h(t)$ = Impulse Response

For $a(t) = \mathrm{Re}[u(t) \exp j\omega_o t]$

$b(t) = \mathrm{Re}[v(t) \exp j\omega_o t]$

$$v(t) = \int_o^t h_L(t-\tau)\ u(\tau) d\tau$$

where $h_L(t) = h(t) \exp(-j\omega_o t)$

SYNTHESIZER PROGRAM

VCO Phase Vector $[\theta_v]$

$$[\theta_v] = [\omega_q]\, t + [\theta_v] + K_v \int_o^t [Z(\tau)]d\tau$$

Standard Signal Phase Vector $[\theta_s]$

$$[\theta_s] = [\omega_s]\, t + [\phi_s]$$

Mixer Output Vector $[\theta_M]$

$$[\theta_M] = U[\theta_S] + E[\theta_V] + W[\theta_M] + [\phi_M]$$

Phase Comparator Reference Signals $[\theta_R]$

$$[\theta_R] = T[\theta_S] + C[\theta_V] + D[\theta_M]$$

Phase Comparator Feedback Signal Vector $[\theta_F]$

$$[\theta_F] = A[\theta_V] + B[\theta_M]$$

where: $[\omega_q]$ = VCO Quiescent Frequency Vector

$[\omega_S]$ = Reference Signal Frequency Vector

$K_V = [K_{Vii}]$ (Diagonal Matrix)

K_{Vii} = VCO Gain Constant, Loop i

$[Z(t)]$ = VCO Input Signal Vector

A, B, C, D, E, T, U, W Defined by Block Diagram

Phase Locked Loop Component Parameters

Loop Filters

$F(S) = [F_{ii}(S)]$ (Diagonal Matrix)

F_{ii} = Filter Transfer Function Loop i

$f(t) = [f_{ii}(t)] = [\mathscr{L}^{-1}\, F_{ii}\,(S)]$

Phase Comparators

Gain Constant

$$K_D = [K_{Dii}] \text{ (Diagonal Matrix)}$$

Normalized Phase Comparator Characteristic

$$[Y] = [g(X)]$$

where: $[X] = [\theta_R] - [\theta_V]$

Define

$$AA = (C-A) + (D-B)\ (I-W)^{-1}\ E$$

$$BB = T + (D-B)\ (I-W)^{-1}\ U$$

$$CC = (D-B)\ (I-W)^{-1}$$

Steady State VCO Frequency Vector

$$[\dot{\theta}_V]_{SS} = -AA^{-1}\ BB\ [\omega_S]$$

Mixer and Reference Frequency Vectors

$$[\theta_M]_{SS} = (I-W)^{-1}\ (U-EAA^{-1}BB)\ [\omega_S]$$

$$[\theta_R]_{SS} = A[\dot{\theta}_V]_{SS} + B\ [\theta_M]_{SS}$$

Transfer Function Matrices

Define: $K = K_D\ K_V$

$$R(S) = (I-AA\ KF(S)/S)^{-1}$$

$$\rho(S) = (KF(S)/S)\ .\ R(S)$$

Closed Loop Transfer Function Matrix To Loop Outputs for Signals Generated

a. At Mixer Outputs:

$$H_M(S) = \rho(S)\ .\ CC$$

b. At Phase Comparator Outputs:

$$H_D(S) = \rho(S)$$

c. At Reference Inputs:

$$H_S(S) = \rho(S)\ .\ BB$$

d. On VCO Outputs:

$$H_V(S) = R(S)$$

Acquisition

Loop Output Phase Error Vector

$$[\theta_{V\varepsilon}] = AA\ [X]$$

Initial Frequency Error Vector

$$[\omega_\Delta] = [\omega_q] + AA^{-1}\ BB\ [\omega_S]$$

Differential Equation

$$[\dot{\theta}_{V\varepsilon}] = [\omega_\Delta] + K_V[Z]$$

where $[Z] = [f(t) * K_D\ [Y]]$

and $[Y] = [g(AA^{-1}\ \theta_{V\varepsilon})]$

1.3 OUTLINE OF THE FINAL REPORT

Section 2 of this report defines the requirements for the computer programs, generated under the ARMM program and intended as the basis for an advanced receiver methodology. These requirements are related to the tasks undertaken by the systems engineer, the configurations of the block diagrams of the various types of receivers and the characteristics of receiver module types. Section 2 also discusses the requirements for the user's manual prepared for use with the ARMM computer programs.

Section 3 provides a description of the signal path computer program and Section 4 describes the synthesizer computer programs developed on this program. Section 5 describes an auxiliary computer program (SPURS) used to generate a file, called by the signal path and synthesizer programs, containing the performance data for a catalog of mixers.

Conclusions and recommendations for potential enhancement of the ARMM computer program are given in Section 6. Section 7 is a glossary defining significant parameters.

SECTION II

ARMM COMPUTER PROGRAM REQUIREMENTS

2.1 SYSTEMS ENGINEERING TASKS

In this section the tasks generally undertaken by the systems engineer are analyzed to determine their impact on the architecture and content of the ARMM computer program and to define the performance parameters required for computation.

2.1.1 Systems Definition, Integration and Subsystems Specification

The r.f. systems engineer operates on system requirements given in terms of operational performance parameters and range and transforms these to subsystem parametric requirements relative to desired transmitter outputs (frequency, waveform and power level) and receiver responses to desired signals. Additionally he specifies undesired transmitter outputs and receiver responses and the degree of suppression required for each subsystem.

Requirements for system maximum and minimum operating range impose a need to determine receiver senstivity (noise figure), dynamic range and intermodulation performance.

Requirements for systems electromagnetic compatibility impose a need to determine receiver intermodulation and spurious response performance.

Requirements related to weapon and aircraft reaction times impose a need to determine receiver signal acquisition time.

Requirements for signal distribution, such as:

(a) a single antenna feeding a number of receivers by means of a multicoupler, or,

(b) a single receiver front end feeding a number of IF channels in a channelized receiver,

imply a need to relate overall performance to the performance of cascaded modules.

Requirements for signal selection or combination such as:

(a) switching a receiver to one of several antennas, or

(b) combining the outputs from several antennas through weighting networks to obtain a desired antenna pattern,

also imply a need to relate overall performance to the performance of cascaded modules. In this case the modules are:

(1) the circuits prior to the receiver, and (2) the receiver circuits.

2.1.2 Proposal Evaluation

R.F. subsystem proposals generally represent a technical optimization yielding a balanced compromise of many specification requirements. Usually, well prepared proposals are quite lengthy, so that the evaluation process, generally carried out under intense time pressure, is quite complex. Despite their great bulk, many proposals do not include sufficient information to demonstrate that required

subsystem performance will be achieved. Often these unconsidered elements of the proposal become the areas of failure to achieve specification compliance, to the mutual distress of the vendor and customer.

When the systems integrator receives proposals for receiver designs from a number of vendors it is necessary to determine:

(a) whether enough information is provided relative to the proposed circuits to permit determination of overall performance and, if so,

(b) whether the overall performance complies with specifications.

The proposed design configurations will usually differ substantially despite attempts by the vendors to satisfy a common set of requirements. The determinations in (a) and (b) permit a comparison of diverse design approaches, a primary task in the proposal evaluation phase of a program.

Requirements for accommodation of a wide variety of receiver configurations implies a need for a flexible method for entry of block diagram information especially when the receiver employs a frequency synthesizer (which has a two dimensional block diagram with a potential for numerous cross connections). Thus a complex network topology problem has to be solved.

The requirement for determination of (a) and (b) implies a need to determine overall performance from performance data of the functional blocks.

2.1.3 Subsystem Development Program Monitoring

The prototype development phase of RF subsystem engineering programs is generally of extended duration, during which there is little interim technical output to indicate progress in compliance with schedule and requirements. There is a need, during the development interval, for interim milestones relating to technical achievement. During this period program technical output becomes available in terms of module performance, which may differ from the performance anticipated in the proposal.

There is thus a need for the ARMM computer program to relate performance of the modules to overall receiver performance. This implies the development of a cascade algorithm for each of the performance parameters computed.

A computer program with this capability permits evaluation of the impact on overall performance associated with the failure of any module to achieve its technical performance goal. This permits exercise of judgement concerning the merit of improving the design of such a module with attendant increased design cost and possible delivery delay, a basic requirement in a design-to-cost engineering environment.

2.1.4 Subsystem Test and Evaluation

Ordinarily, testing a receiver for specification compliance can be effected by means of measurements made using test equipment connected to the input and/or output terminals. No knowledge is required of internal module design or performance.

Tests of compliance with spurious response requirements of synthesized receivers can be extraordinarily extensive. A complete test would require the receiver to be set to each frequency assignment and the receiver response noted at each setting as a high level interferer is swept through the band. Since some receivers may afford hundreds of thousands of frequency assignments, the frequency search is often abridged and the complete spurious response performance is not assessed.

The effort required to obtain a complete assessment of receiver spurious response performance can be greatly diminished if use if made of internal module performance information. The worst case frequency for each spur product type may be computed from this information so that overall compliance with spur response requirements may be demonstrated with a small number of measurements on signals at these computed frequencies. In the event of non-compliance, require corrective action is readily determined from the measurement information.

2.1.5 Summary

Based on the brief analysis undertaken in this section it is concluded that:

(a) The ARMM program is required to compute receiver sensitivity, dynamic range, intermodulation, spurious repsonse and signal acquisition performance.

(b) Cascade algorithms are required for the performance parameters so that ARMM overall performance computations may be obtained from module parameter information.

(c) The ARMM program is required to be sufficiently flexible to accommodate the wide variety of receiver block diagram configurations and the extensive range of module parameters characteristic of the current receiver art.

2.2 RECEIVER TYPES

Receivers are characterized by their block diagram configurations defined in terms of the types of modules employed and their permissible methods of interconnection. In this section, the various receiver types are considered to determine the extent of the library of module types that the computer program is required to model.

2.2.1 Crystal Video Receiver (Figure 1A)

The crystal video receiver consists of a predetection section and a baseband or post detection section. The predetection section generally contains a filter for selectivity. The baseband signal is generally filtered and amplified.

The module types employed in crystal video receivers are:

(a) linear attenuator (fixed or variable)

(b) r.f. filter (fixed or tunable)

(c) detector

(d) baseband (post-detection) amplifier

(e) baseband filter

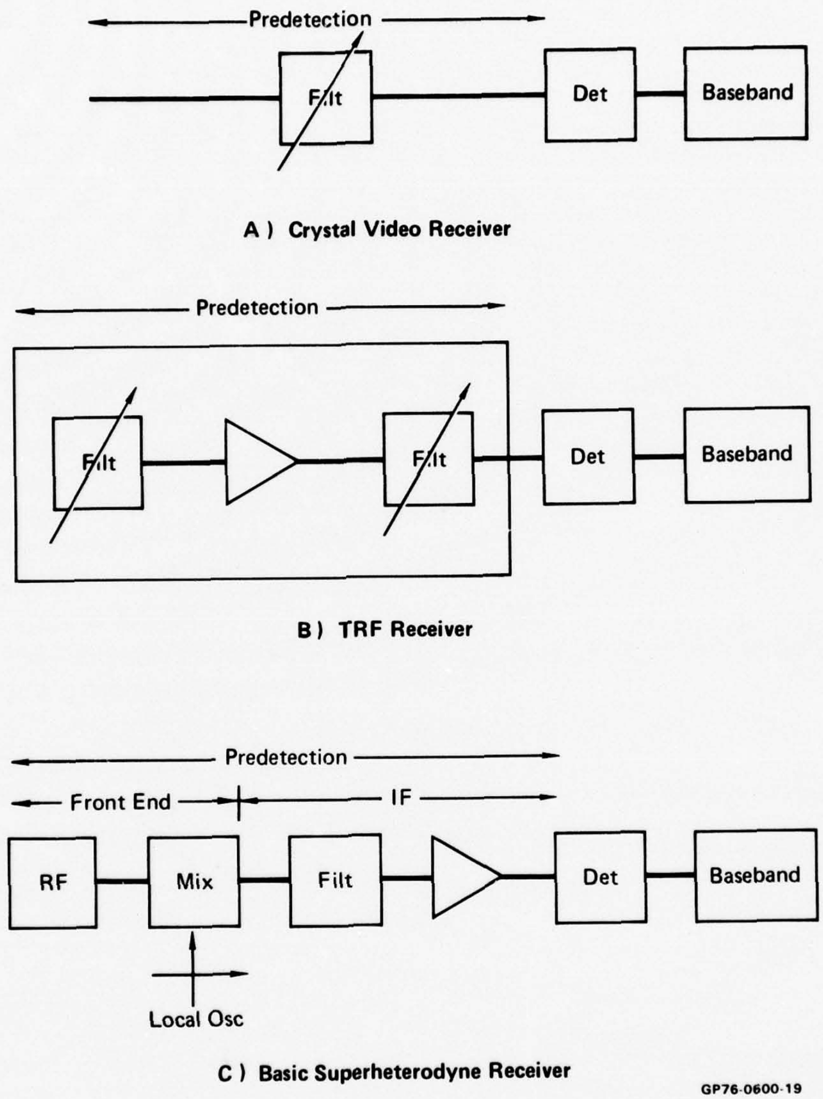


Figure 1. Receiver Configurations

2.2.2 TRF (Tuned Radio Frequency) Receiver (Figure 1B)

The TRF receiver differs from the crystal video receiver in that it provides r.f. amplification to the predetection signal.

The module types employed in TRF receivers are those listed in 2.2.1 and:

(f) r.f. amplifier

2.2.3 Superheterodyne Receiver

In a TRF receiver the ability to select desired signals within an operating band requires use of a tuneable filter with tracked poles and zeros so as to provide a prescribed characteristic relatively independent of filter tuning. The difficulty of this problem results in poor receiver selectivity, filter mis-tuning, waveform distortion and relatively large component volume and weight. The Superheterodyne receiver, invented by Major E. H. Armstrong in 1918, circumvents the problem by means of a frequency conversion process. A non-tuneable filter with controlled selectivity characteristic is employed with a pass-band that is outside the receiver operating frequency band. A tuneable oscillator heterodynes or converts the signals in the operating band to a frequency range that encompasses the filter pass-band. Refer to Figure (1C). Selection of the desired signal is accomplished by choice of the oscillator frequency so that the frequency of the desired-signal is converted to a frequency within the filter pass-band.

Superheterodyne receiver block diagrams are divided into sections based on signal frequency content. The r.f. section includes all blocks from the receiver input through the mixer. The subsequent stages prior to the detector comprise the intermediate frequency (i.f.) section wherein signals are within the fixed filter pass-band. The detected signals are processed in the baseband section of the receiver.

The superheterodyne receiver block diagram is divided into: (1) the signal path, employing the modules listed in 2.2.1 and 2.2.2 and:

(g) mixer

and (2) injection signals (the local oscillators for the mixers).

The types of injection signals are classified as

- o fixed frequency
- o tunable
- o swept
- o stepped (synthesizer)

2.3 COMPUTER PROGRAM ARCHITECTURE

2.3.1 Signal Path Computer Program

From the foregoing it is concluded that the receiver types listed in Section 2.2 may be modeled by a signal path program operating on a library of module types that includes linear attenuators, r.f. filters, r.f. amplifiers, mixers, detectors, baseband filters and baseband amplifiers. These modules are interconnected in a cascade arrangement and the signal path computer program is required to operate on them as they occur in any sequence.

The performance parameters treated by the signal path program are sensitivity, dynamic range, intermodulation, and spurious repsonse performance (the latter being applicable to superheterodyne receivers). An additional performance parameter that is often of interest is the effect of the receiver filters on the waveform of a modulated signal. The signal path program also computes receiver waveform response.

The signal path program accommodates fixed and tunable injection signals directly and swept injection signals indirectly, accounting for the swept oscillator phase by means of a corresponding signal phase modulation to determine the receiver waveform response. Stepped injection signals are treated separately by a synthesizer computer program.

To minimize the complexity of the signal path program, block diagrams that do not permit modeling in terms of a simple cascade interconnection are not accommodated directly. Thus, multiplexed receivers are not treated in their entirety. Each separate signal path may be entered as a different receiver. Cases where interconnection affects sensitivity performance are treated through the addition of the "combiner" to the library of model types.

Limitation to a single cascade interconnected signal path eliminates direct modeling of all types of r.f. feedback. In many such cases the feedback loop may be reduced to an equivalent circuit consisting of a simple cascade of modules contained in the signal path program library.

2.3.2 Synthesizer Program

Synthesizers are employed to tune receivers to a set of frequencies that are rational fractions of a reference frequency standard. They thus achieve frequency agility while providing the stability and accuracy of a frequency standard. Consequently synthesizers are widely used in military receivers to permit rapid tuning to a set of assigned frequencies.

Synthesized injection signals are subject to phase modulation by spurious and noise modulating signals generated in the synthesizer. Consider an injection signal $e_o(t)$ to a mixer at frequency ω_o (rad/sec) phase modulated by a sinusoid with peak phase deviation ϕ_P (rad) and frequency δ (rad/sec).

$$e_o(t) = E_o \cos (\omega_o t + \phi_P \cos \delta t + \phi_o) \tag{1}$$

where $\phi_P << 1$

The injection signal may be written in the form

$$e_o(t) = E_o\{\cos(\omega_o t + \phi_o)\ \cos(\phi_P \cos\delta t) - \sin(\omega_o t + \phi_o)\ \sin(\phi_P \cos\delta t)\}$$

For $\phi_P << 1$, $\cos(\phi_P \cos\delta t) = J_o(\phi_P) + 2\sum_1^{\infty} (-1)^n J_{2n}(\phi_P) \cos 2n\delta t \simeq J_o(\phi_P) \simeq 1$

$$\sin(\phi_P \cos\delta t) = 2\sum_1^{\infty} (-1)^{n+1} J_{2n-1}(\phi_P)\ \cos(2n-1)\delta t \simeq 2J_1(\phi_P)\ \cos\delta t$$

$$\simeq \phi_P \cos\delta t$$

where $J_n(X)$ is the Bessel Function of order n.

$$e_o(t) = E_o\{\cos(\omega_o t + \phi_o) - \phi_P \sin(\omega_o t + \phi_o)\ \cos\delta t\}$$

$$= E_o\{\cos(\omega_o t + \phi_o) - (\phi_P/2)\ \sin\ [(\omega_o + \delta)t + \phi_o] - (\phi_P/2)\ \sin[(\omega_o - \delta)t - \phi_o]\} \qquad (2)$$

Consider an input signal, $e_S(t)$ to the mixer with amplitude E_S and frequency ω_S (rad/sec) yielding an output signal at frequency ω_I, $\omega_I = |\omega_o \pm \omega_S|$. The output signal, derived from the first term of (2) is

$$e_I(t) = E_o E_S \cos(\omega_o t + \phi_o)\ \cos(\omega_S t + \phi_S)$$

$$= E_o E_S/2 \cos(\omega_I t + \phi_I) + \text{image term}$$

where $\phi_I = |\phi_o \pm \phi_s|$

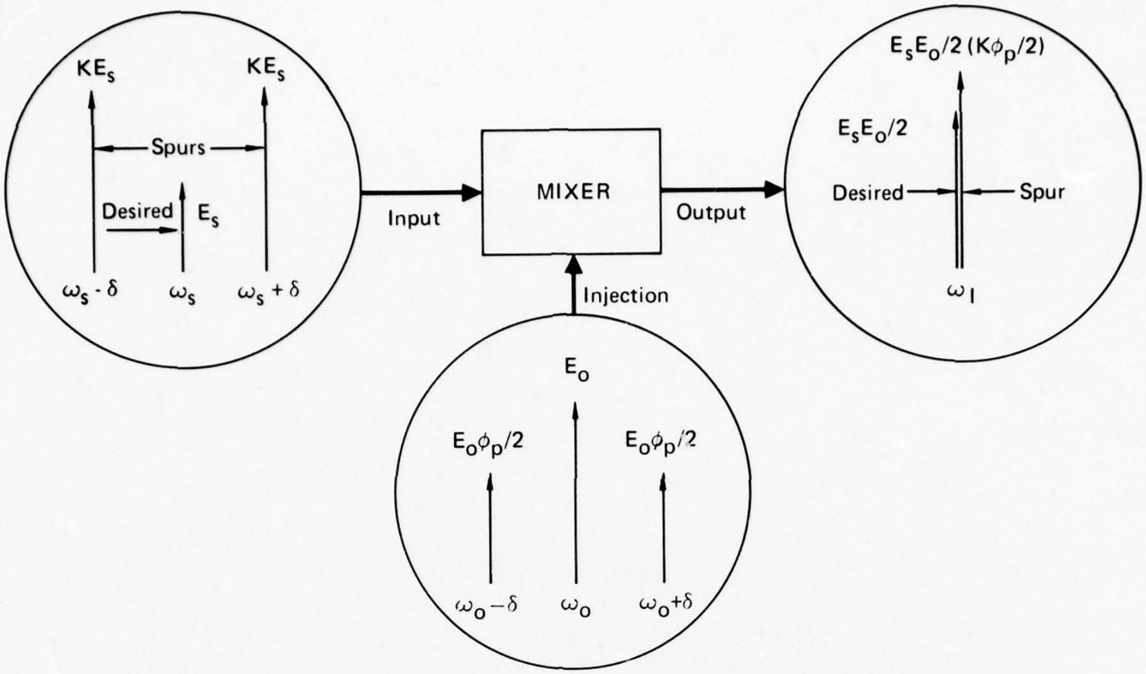
Consider spurious input signals at frequency $\omega_S \pm \delta$ and amplitude KE_S (K >> 1). Each such signal combines with one of the terms of (2) to yield an output at ω_I:

$$-(E_o\phi_P/2)\cdot KE_S\cdot\sin[(\omega_o\pm\delta)t\pm\phi_o]\cos[(\omega_S\pm\delta)t\pm\phi_{Sp}]$$

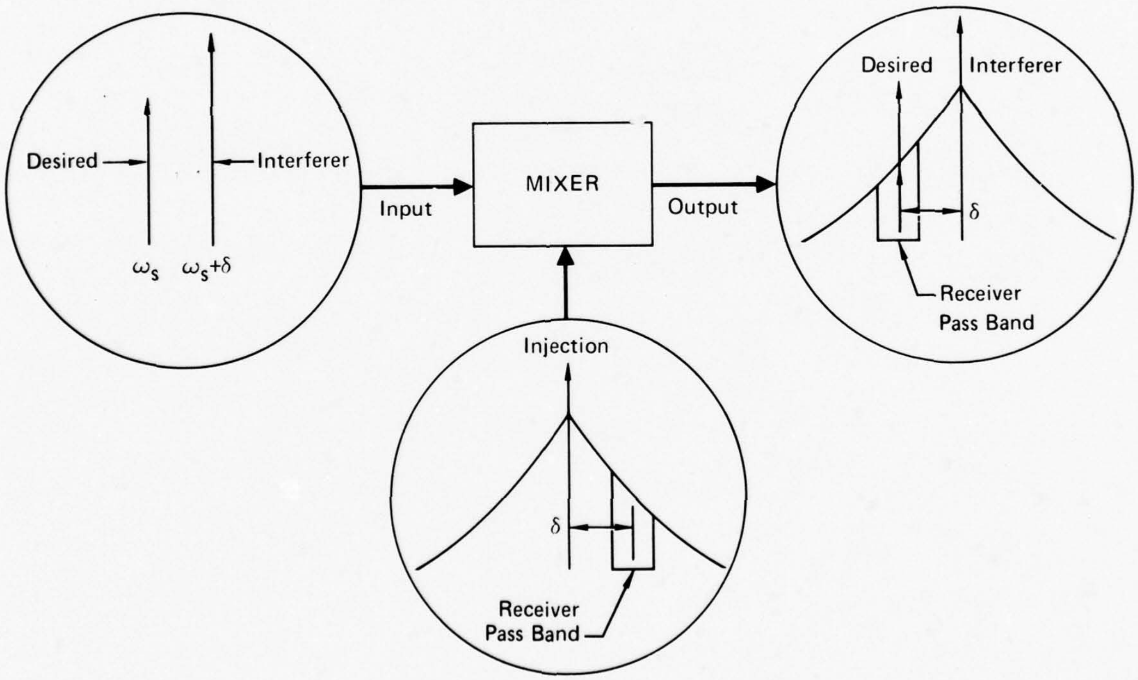
$$=-(E_oE_S/2)(K\phi_P/2)\sin[\omega_I t\pm\phi-\phi_{Sp}]+ \text{Other Term}$$

Thus each component that phase modulates the injection signal gives rise to a pair of spurious responses (Figure 2A). Phase modulation of the injection signal **by a noise spectrum results in a corresponding noise spectrum** about a strong interfering signal as shown in Figure 2B. That portion of the noise spectrum that is near the desired output signal degrades receiver performance. Hence noise phase modulation of the injection signal provides a limitation on the permissible frequency proximity of the desired signal to a strong interferer.

It is concluded that spurious and noise modulation on the output signal are essential performance parameters required for computation by the synthesizer program.



a) Receiver Spurious Response Due to Phase Modulated Injection Signal



b) Effect of Noise Phase Modulation on Injection Signal

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Figure 2. Phase Modulation of Injection Signal

Synthesizer block diagrams consist of interconnected phase locked loops, generically similar to that shown in Figure 3. The VCO output of any loop may feed another loop at either of the two input points (phase detector input or mixer input). The block diagram may thus exhibit considerable complexity, being two dimensional with a potential for numerous cross connections (as distinguished from the simple cascade interconnection of signal path modules). An essential feature of the synthesizer program is the ability to model a cross connected two dimensional block diagram. To accommodate applications where system reaction time is a significant performance parameter, the acquisition characteristics of the interconnected phase locked loops are required to be computed for the synthesizer.

The modules to be modeled are those shown in Figure 3: VCO, Mixer, Frequency Divider (and Multiplier), Phase Comparator and Filter.

2.4 COMPUTER PROGRAM FEATURES

The library of components modeled in the signal path and synthesizer computer programs and the performance parameters required for computations have been listed in previous sections. In this section features of the computer programs are discussed that enhance their utility as the basis for an advanced methodology for systems employing receivers.

2.4.1 Flexibility

Within the limitation of the signal path computer program, wherein, receivers are modeled as a cascade connection of as many as 30 modules, free play is permitted of the sequence of module types and an essentially arbitrary range of parameter values is accommodated.

Similarly the synthesizer computer program accommodates all block diagrams consisting of interconnected phase locked loops and an arbitrary range of parameter values. (program size limitations are: 12 phase locked loops, 12 mixers, 5 outputs and 2 standard frequencies).

2.4.2 Interaction

The broad flexibility of the computer programs and the wide range of performance parameters computed would ordinarily lead to a complex and extensive sequence of directions for program operation and data entry and management. To unburden the user, the programs have been made interactive so that they communicate to the user their own instruction sequences, tailored to his requirements for performance parameter computation and the number and arrangement of module types entered.

Instructions to the user are self-explanatory, defining dimensions for data entry and performance printouts. Computation options are offered to the user and only the appropriate data required to effect the desired computations are requested of the user. Likewise, the data printout is tailored to the user requirements.

2.4.3 Data Entry, Edit and Storage

The user is guided by a computer generated questionnaire to enter data related to the block diagram configuration and module parameter values appropriate to the performance computations requested.

Upon completion of data entry a printout of the data entered is generated and the user is requested to verify that the data printed is correct. An affirmative response causes the data to be entered into a file for subsequent recall. A negative response brings the data edit sequence into operation permitting the user to change the block diagram configuration and/or the parameters of selected modules. The data edit capability permits correction of errors made in the data entry sequence and determination of the impact of any module parameter perturbations on overall receiver performance.

A printout is made of the changed data and the user is again asked to verify that the data is correct. When the user response is affirmative, the performance computations requested are carried out.

2.5 USER'S MANUAL

The user's manual has been written to satify two requirements:

(a) A handbook containing a tutorial exposition of the subject to serve as a training document for aerospace receiving systems engineers.

(b) A set of instructions for the program user.

Accordingly the user's manual has two parts. The first part which is essentially tutorial, derives all of the algorithms employed in the computer programs. The second part contains detailed user instructions cross-referenced to appropriate sections in the first part.

The level of preparation assumed for the reader of the user's manual is equivalent to that provided in a first course in linear electric circuits generally given during the junior year in the Electrical Engineering curriculum. Thus, an understanding of the Fourier and Laplace transform, matrix manipulation, and the elements of set theory is assumed for the reader. Although a suitable list of references is provided, the material is self-contained and a reader with the assumed level of preparation need not look elsewhere to follow the material presented therein.

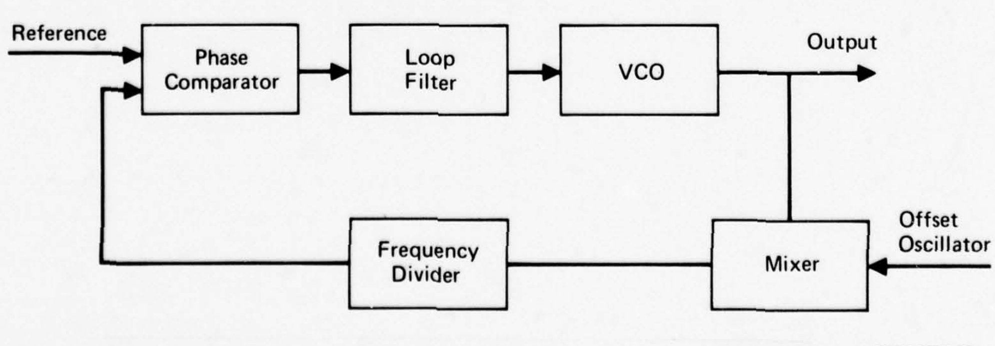

Figure 3. Phase Locked Loop Block Diagram

SECTION III

RECEIVER SIGNAL PATH COMPUTER PROGRAM, RXSG

3.1 PRELIMINARY INFORMATION

The user is asked to respond (yes or no) to a sequence of printed questions. Each request for information or user guidance statement printed is indicated by an asterisk. Each user response discussed is underlined.

3.1.1 Previous File Status

* HAS A FILE BEEN OPENED PREVIOUSLY FOR THE DATA FOR THIS RECEIVER?

If no† a new file is opened.

If yes the data in the file is read into the computer work memory.

3.1.2 Desired Computations

* PERFORM FREQUENCY PLAN COMPUTATIONS?

* PERFORM NOISE FIGURE COMPUTATIONS?

* PERFORM DYNAMIC RANGE COMPUTATIONS? D

* PERFORM INTERMOD COMPUTATIONS? I

* PERFORM SPUR PERFORMANCE COMPUTATIONS? S

* COMPUTE SIGNAL WAVEFORM?

The computations corresponding to those questions for which the user provides a yes response are carried out in sequence.

If a yes response is given to the question on spur response computation an auxiliary program containing a mixer catalog file is called and its contents are read into the signal path computer program work memory. Instructions for data entry and update of the mixer catalog program are given in section 5.

3.2 DATA ENTRY AND PRINTOUT

3.2.1 Data Entry

If the response to the question in section 3.1.1 is no the user is prompted with a sequence of requests for information relative to the parameters of the receiver modules. The user is required to provide information as follows:

a) The number of blocks in the signal path block diagram.
b) The type of each block selected from the library listed in Table 1.
c) For each block type, the information listed in Table 1.
   c.1) For filters, information for item 5 of Table 1, relating to Gain (db) and Noise Bandwidth (MHZ), is obtained through the use of an auxiliary computer program. This program should be used to determine these values for each filter before filter data entry for the signal path computer program is attempted.

† For questions requiring a literal response, if the response is unacceptable, the question is repeated. If unacceptable responses are given four times the program terminates after printing: **FOUR TYPING MISTAKES, PROGRAM BOMBS.**

Table 1. Data Requirements for Receiver Block Types

Block Type	Required Data
Linear	1. Gain Fixed or Variable?
	2a. If Fixed; Gain (db)
	2b. If Variable: Max Gain (db); Min Gain (db)
Filter	1. Fixed or Tuneable?
	2. Number of Poles and Zeros
	3. Gain Constant
	4a. If Fixed: Pole and Zero Locations
	4b. If tuneable: Pole and Zero Locations - for Highest and Lowest Tuned Frequencies
	5*. Gain (db) , Noise Bandwidth (MHz)
	6. If Gain Greater Than 0 db:
	6a. Noise Figure (db)
	6b. Second, Third Order Intermodulation Intercepts (dbm), [I]
	6c. 1db Compression Level (dbm) [D]
Amplifier	1. Gain (db) , Noise Figure (db)
	2. Second, Third Order Intermodulation Intercepts (dbm) [I]
	3. 1 db Compression Level (dbm) [D]
Mixer	1**. Mixer Catalog Number
	2a. Noise Figure (db)
	2b. Second, Third Order Intermodulation Intercepts (dbm) [I]
	2c. 1 db Compression Level (dbm) [D]
	3. Min-Max Osc. Frequency (MHz) [S]
	4. Sideband Converted (Upper, Lower or Both) [S]
Detector	1. Detector Type (AM Envelope, AM Sq. Law, PM, FM)
Combiner	1. Number of Additional Inputs
	2. For Desired Input:
	2a. Gain (dB) Noise Figure (dB)
	2b. Second, Third Order Intermodulation Intercepts (dbm) [I]
	2c. 1 db Compression Level (dbm) [D]
	3. For Each Additional Input:
	3a. Gain (dB), Noise Figure (dB)

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Notes:

** Option available to print mixer catalog file and performance data

* Obtained as output of auxiliary filter computer program

[S] Required only if spur performance computations are to be performed

[I] Required only if intermodulation computations are to be performed

[D] Required only if dynamic range computations are to be performed

Brackets indicate referenced sections of the manual.

c.2) For filters: "Gain" is the available power gain; "Transfer Function" is the voltage gain with open circuited output.

d) For receivers without mixers; center frequency of input filter passband. For receivers with mixers; center frequency of last IF.

e) If waveform computations are required: carrier frequency of input signal.

f. For receivers with automatic gain control or variable gain, each block with a gain variation is modeled by adding, at its input, a linear block with variable gain. The minimum and maximum gain for each such linear block is required.

* INPUT: NUMBER OF BLOCKS (INTEGER ANSWER: 1 TO 30)

If the answer is an integer **N**, the user is asked the module type for each block from 1 through N in sequence. A list is presented of the library of acceptable block types:

* ACCEPTABLE BLOCK TYPES: LINEAR, FILTER, AMPLIFIER, MIXER, DETECTOR, COMBINER

* INPUT: TYPE, BLOCK I

I is an integer given in sequence from 1 to N.

The program operates interactively, asking for module parameters appropriate to the block type indicated by the user in accordance with the interactive sequence indicated in Figure 4.

A running count is made of the number of mixers and filters. If a detector is included in the set of blocks, the number of post-detection filters is counted. (The number of predetection filters is obtained by subtraction.)

Blocks labeled (D) are required for dynamic range computations only and are bypassed if the question in Section 3.1.2 related to dynamic range computations is answered negatively. Similarly blocks labeled (I) and (S) are bypassed if the appropriate questions in Section 3.1.2 related to intermodulation and spurious response performance, respectively, are answered negatively.

When any of the paths in Figure 4 arrives at an exit triangle (▼) the program asks for the type of the next block and the process is repeated until data has been entered for all N blocks.

* ENTER CENTER FREQUENCY (MHZ) OF LAST IF

* ENTER INPUT FILTER PASSBAND MID FREQUENCY (MHZ)

When data has been entered for the last (NTH) block the user is requested to enter the center frequency of the last IF. If there are no mixers in the receiver, the question is changed to request the center frequency of the first r.f. filter. The information is used to reconstitute the receiver frequency plan and compute front end second order intermodulation and spurious response performance.

* ENTER WAVEFORM CARRIER FREQUENCY (MHZ)

If a <u>yes</u> response was given to the question on signal waveform listed in Section 3.1.2, the user is asked to enter the input signal carrier frequency.

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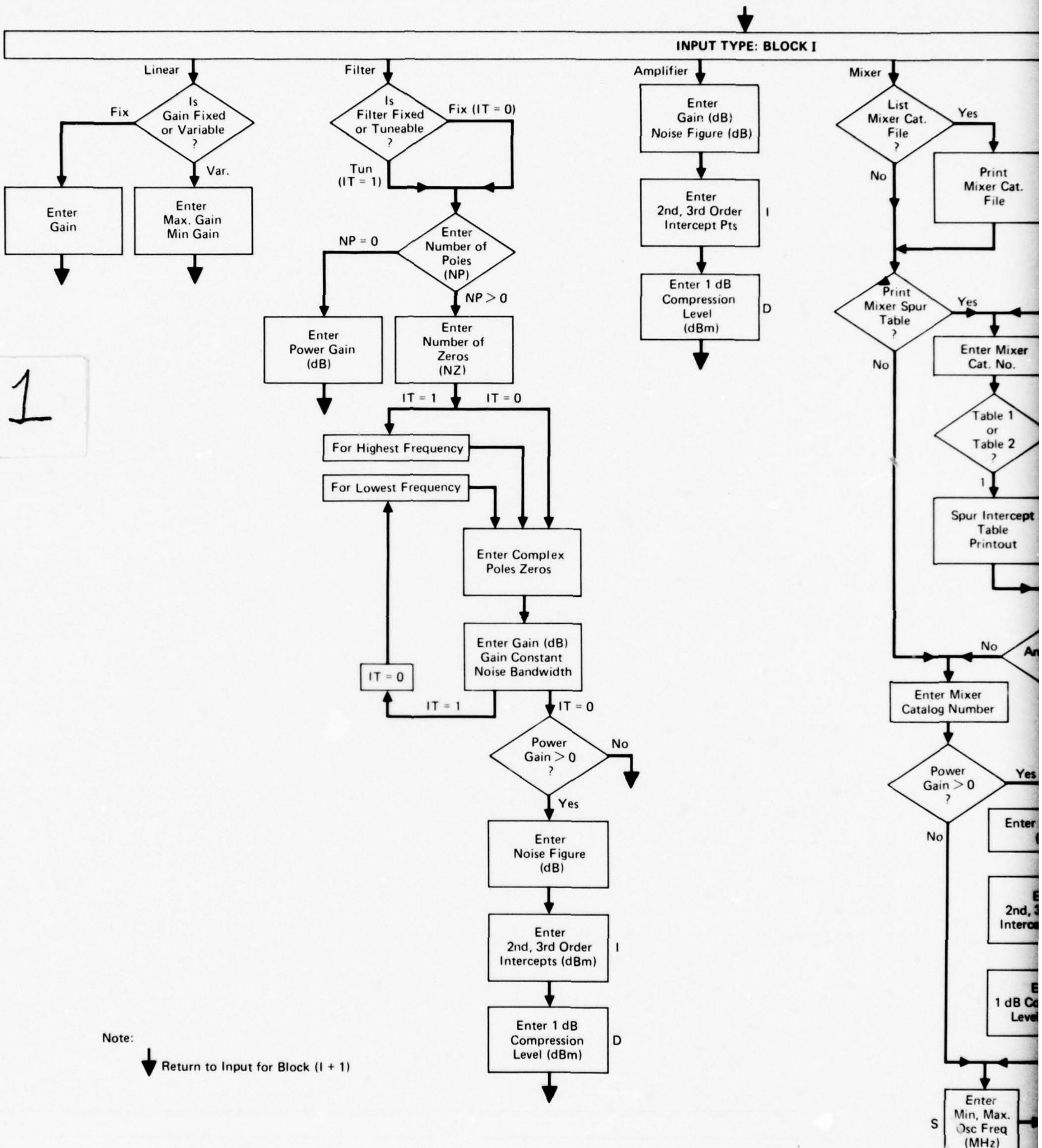
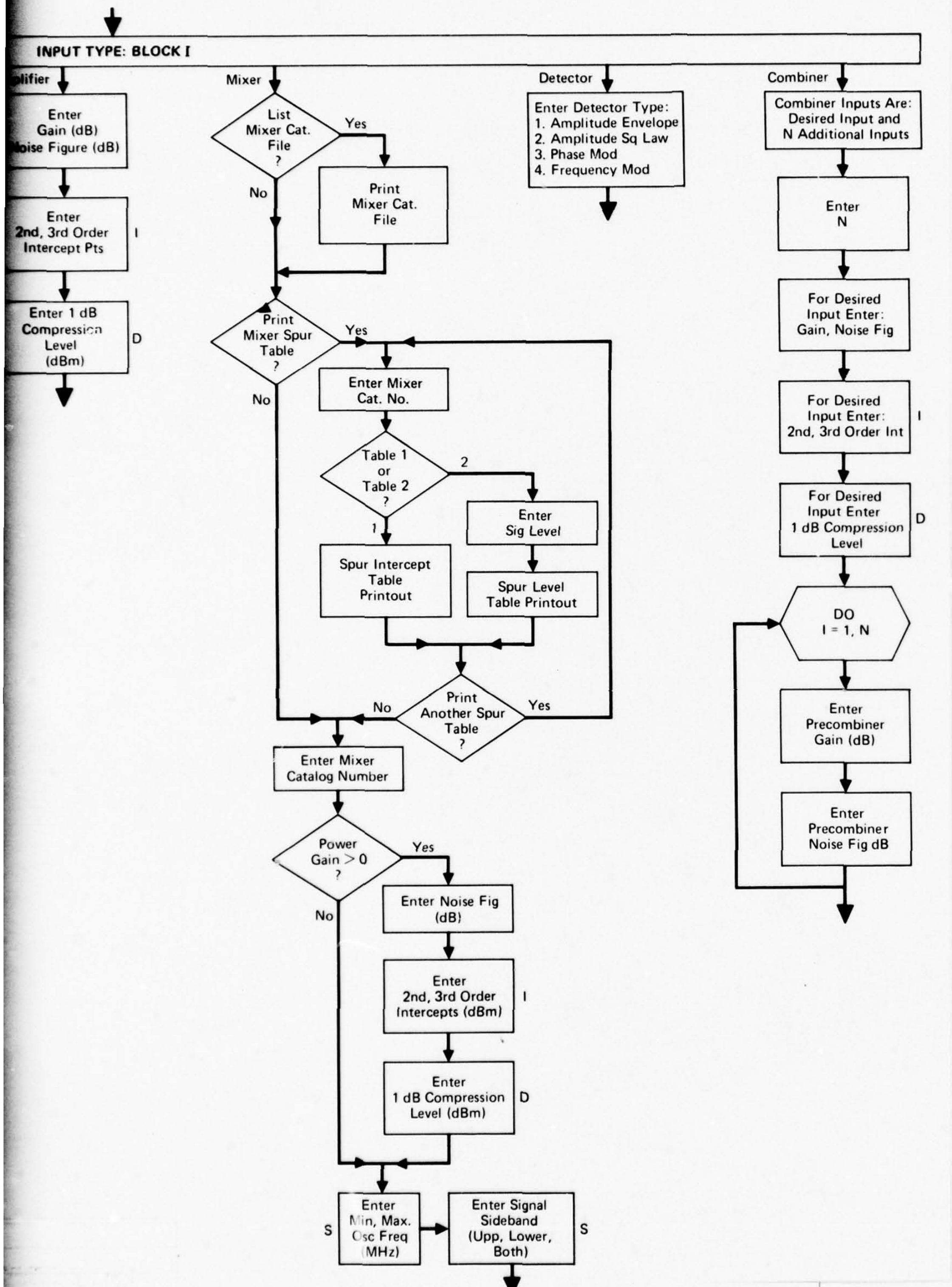


Figure 4. Interactive Data Entry Parameter Questionnaire

2



INPUT TYPE: BLOCK I
plifier
Enter Gain (dB) Noise Figure (dB)
Enter 2nd, 3rd Order Intercept Pts
I
Enter 1 dB Compression Level (dBm)
D
Mixer
List Mixer Cat. File ?
Yes
No
Print Mixer Cat. File
Print Mixer Spur Table ?
Yes
No
Enter Mixer Cat. No.
Table 1 or Table 2 ?
2
1
Enter Sig Level
Spur Intercept Table Printout
Spur Level Table Printout
Print Another Spur Table ?
No
Yes
Enter Mixer Catalog Number
Power Gain > 0 ?
Yes
No
Enter Noise Fig (dB)
Enter 2nd, 3rd Order Intercepts (dBm)
I
Enter 1 dB Compression Level (dBm)
D
Enter Min, Max. Osc Freq (MHz)
S
Enter Signal Sideband (Upp, Lower, Both)
S
Detector
Enter Detector Type:
1. Amplitude Envelope
2. Amplitude Sq Law
3. Phase Mod
4. Frequency Mod
Combiner
Combiner Inputs Are: Desired Input and N Additional Inputs
Enter N
For Desired Input Enter: Gain, Noise Fig
For Desired Input Enter: 2nd, 3rd Order Int
I
For Desired Input Enter 1 dB Compression Level
D
DO I = 1, N
Enter Precombiner Gain (dB)
Enter Precombiner Noise Fig dB
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onnaire

Preceding Page Blank - Filmed

3.2.2 Data Printout

In accordance with the question asked in Section 3.1.1, data is entered for computation either by reading a previously generated data file or by the responses given to the interactive questionnaire described in Section 3.2.1. In either case the data is available for printout.

* BYPASS DATA PRINTOUT?

An option is available to eliminate the data printout. If the response is no the receiver signal path data is printed in accordance with the sample† given in Figure 6. If questions related to computation of Dynamic Range [D] , Intermodulation [I], or Spur [S] , performance in Section 3.1.2 are answered no, corresponding sections of the data printout are omitted.

3.3 DATA CORRECTION

Three data correction processes are provided which permit change of all data entered:

a) Add-a-block which permits increase in the number of blocks.
b) Block data correction which permits change of all data associated with any of the blocks.
c) Other data correction which permits change of data not associated with any block.

After completion of data printout the user is asked:

* IS DATA CORRECT?

If yes, the data is entered into a file for future use.

If no, the data correction process is executed.

3.3.1 Add-A-Block

3.3.1.1 New Block Definition - The user is asked:

* ADD A NEW BLOCK?

If the number of blocks, N, is required to be increased or an existing block type is to be changed to a filter, mixer, combiner or detector the question should be answered yes.

If no, the program advances to Section 3.3.2.

If yes, an interactive sequence of questions and computer operations is executed:

* ENTER NUMBER OF NEW BLOCK

The number entered, I, may be any integer from 1 to N+1.

* ACCEPTABLE BLOCK TYPES: LINEAR, FILTER, AMPLIFIER, MIXER, DETECTOR, COMBINER

* INPUT: TYPE, BLOCK I

a) If the block type entered is Detector and another block type is detector:

* ILLEGAL ENTRY: TWO DETECTORS NOT PERMITTED

The program returns to:

* ADD A NEW BLOCK? and the questions of this Section (3.3.1.1) are reiterated.

If no other block type is detector, a process of renumbering block data is executed (Section 3.3.1.2)

†The sample corresponds to the block diagram of Figure 5.

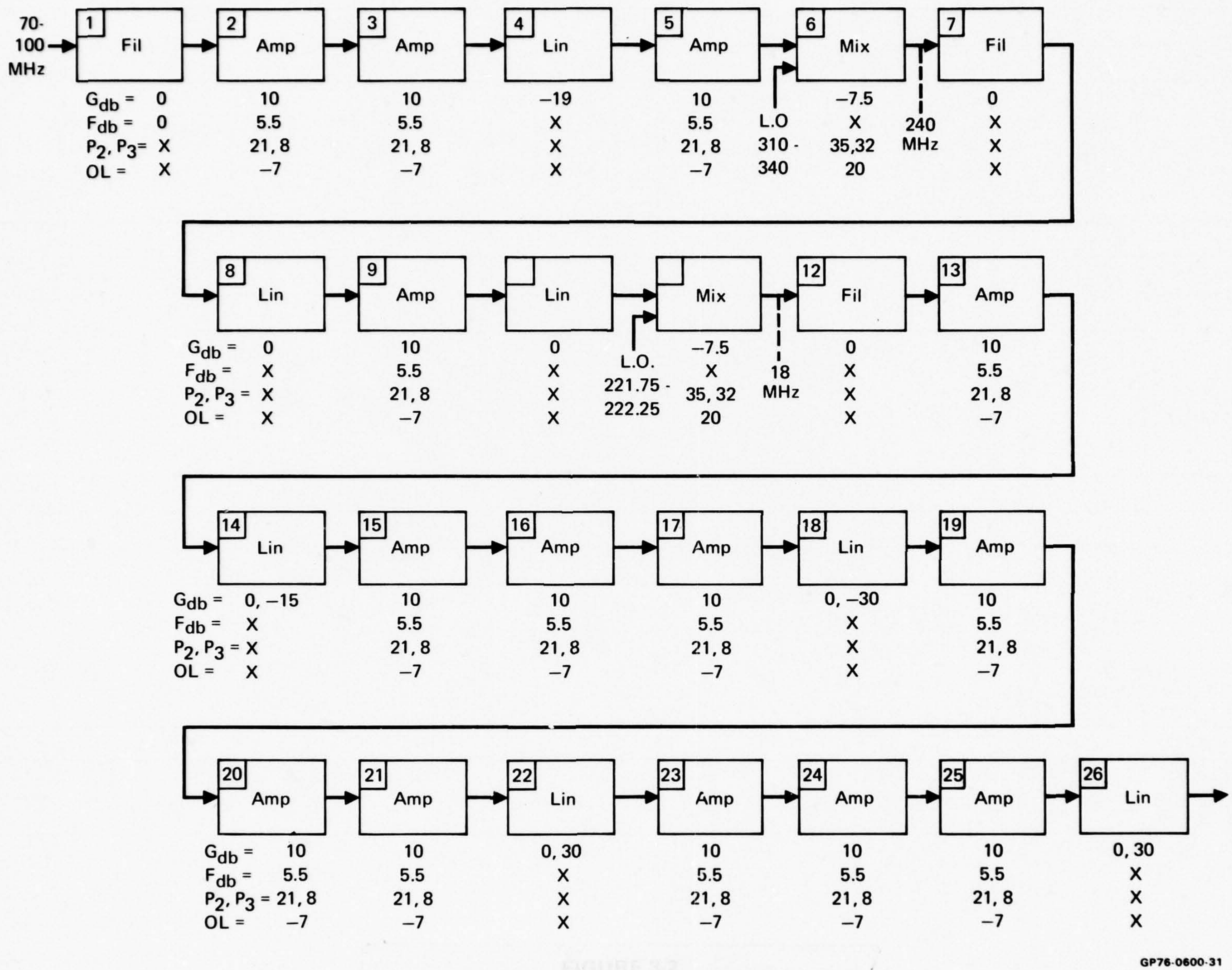

Figure 5. Sample Receiver Block Diagram

++++++++++++++++++++++++ BLOCK DATA ++++++++++++++++

	MAXIMUM GAIN		MINIMUM GAIN				
BLK	G	F	G	F	OL	P2	P3
1	0.0	0.0	0.0	0.0	999.0	99.0	99.0
2	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
3	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
4	-19.0	19.0	-19.0	19.0	999.0	99.0	99.0
5	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
6	-7.5	7.5	-7.5	7.5	20.0	35.0	32.0
7	0.0	0.0	0.0	0.0	999.0	99.0	99.0
8	0.0	0.0	0.0	0.0	999.0	99.0	99.0
9	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
10	0.0	0.0	0.0	0.0	999.0	99.0	99.0
11	-7.5	7.5	-7.5	7.5	20.0	35.0	32.0
12	0.0	0.0	0.0	0.0	999.0	99.0	99.0
13	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
14	0.0	0.0	-15.0	15.0	999.0	99.0	99.0
15	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
16	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
17	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
18	0.0	0.0	-30.0	30.0	999.0	99.0	99.0
19	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
20	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
21	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
22	0.0	0.0	-30.0	30.0	999.0	99.0	99.0
23	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
24	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
25	10.0	5.5	10.0	5.5	-7.0	21.0	8.0
26	0.0	0.0	-30.0	30.0	999.0	99.0	99.0

G=GAIN(DB),BLOCK I
F=NOISE FIGURE(DB),BLOCK I
NOTE:F=LOSS(DB) FOR AN ATTENUATOR
P2,P3=SECOND,THIRD ORDER INTERCEPTS(DBM),BLOCK I
OL=1-DB COMPRESSION LEVEL

Figure 6. Data Printout for Receiver Shown in Figure 5.

```
++++++++++++++++++++ MIXER DATA ++++++++++++++++++++

LIST MIXER CATALOG FILE?(ANSWER YES OR NO)
?YES
MIXER       MANUF      CAT. NO.    P-OSC(DBM)
  1        RELCOM      M14A          7.
  2        RELCOM      M9E          27.
  3        RELCOM      M1            7.
  4        BLANK       BLANK            99
  5        BLANK       BLANK            99
  6        BLANK       BLANK            99
MIXER SPUR PRODUCT DATA IS TABULATED IN TWO WAYS:
SPUR PRODUCT INTERCEPTS (TABLE 0) OR
SPUR PROD.CONVERSION LOSS FOR GIVEN SIGNAL LEVEL(TABLE 1)
PRINT MIXER SPUR TABLE? (ANSWER YES OR NO)
?YES
ENTER 1 MIXER NUMBER FROM CATALOG AND
SPUR TABLE DESIRED
EXAMPLE:6,0
?3,0
MIXER       MANUF      CAT. NO.    P-OSC(DBM)
  3        RELCOM      M1            7.
CONVERSION LOSS=  7.5DB
SPUR TABLE 0
J/K     0      1      2      3      4      5      6      7      8
 0    99.0  -36.0  -45.0  -49.0  -60.0  -51.0  -63.0  -59.0  -61.0
 1    24.0    0.0   35.0   13.0   40.0   24.0   45.0   28.0   49.0
 2    63.0   63.0   64.0   60.0   61.0   54.0   59.0   54.0   59.0
 3    23.5   22.0   24.5   15.0   28.5   13.5   27.0   12.0   27.0
 4    18.7   20.0   18.7   19.3   19.3   18.3   18.7   18.3   20.0
 5    12.5   10.0   12.5    7.7   12.5    7.0   12.5    6.2   12.0
 6     8.0    8.0    8.0    8.0    8.0    8.0    8.0    8.0    8.0
 7     5.0    5.0    5.0    5.0    5.0    5.0    5.0    5.0    5.0
PRINT ANOTHER SPUR TABLE?(ANSWER YES OR NO)
?YES
ENTER 1 MIXER NUMBER FROM CATALOG AND
SPUR TABLE DESIRED
EXAMPLE:6,0
?3,1
MIXER       MANUF      CAT. NO.    P-OSC(DBM)
  3        RELCOM      M1            7.
CONVERSION LOSS=  7.5DB
SPECIFY MIXER SIGNAL INPUT LEVEL (DBM)
?-10.
SPUR TABLE 1
J/K     0      1      2      3      4      5      6      7      8
 0    99.0   26.0   35.0   39.0   50.0   41.0   53.0   49.0   51.0
 1    24.0    0.0   35.0   13.0   40.0   24.0   45.0   28.0   49.0
 2    73.0   73.0   74.0   70.0   71.0   64.0   69.0   64.0   69.0
 3    67.0   64.0   69.0   50.0   77.0   47.0   74.0   44.0   74.0
 4    86.1   90.0   86.1   87.9   87.9   84.9   86.1   84.9   90.0
 5    90.0   80.0   90.0   70.3   90.0   68.0   90.0   64.8   88.0
 6    90.0   90.0   90.0   90.0   90.0   90.0   90.0   90.0   90.0
 7    90.0   90.0   90.0   90.0   90.0   90.0   90.0   90.0   90.0
PRINT ANOTHER SPUR TABLE?(ANSWER YES OR NO)
?NO
MIX    CAT    BLK    FOMIN      FOMAX     SB
 1      3      6     310.000    340.000    LOW
MIX    CAT    BLK    FOMIN      FOMAX     SB
 2      3     11     221.750    222.250    UPP

CAT=MIXER CATALOG NUMBER
BLK=MIXER BLOCK NUMBER
FOMIN,FOMAX=OSCILLATOR MINIMUM,MAXIMUM FREQUENCIES(MHZ)
SB=SIGNAL SIDEBAND
NOTE:SB=LOW(UPP)MEANS SIGNAL INPUT FREQUENCY IS
BELOW(ABOVE) OSCILLATOR FRQUENCY
```

Figure 6. Data Printout for Receiver Shown in Figure 5 (Continued)

```
+++++++++++++++++++++++  FILTER DATA  ++++++++++++++++

 3 PREDETECTION FILTERS:      0 BASEBAND FILTERS

FILTER NO.: 1   BLOCK NO.:  1   GF= .36140E+10      BW=      40.000

              POLES( MHZ*2*PI)                      ZEROS( MHZ*2*PI)
NO.            REAL          IMAG                     REAL          IMAG
  1      -.56832E+02     .64906E+03       0.                 0.
  2      -.56832E+02    -.64906E+03       0.                 0.
  3      -.36997E+02     .42253E+03       0.                 0.
  4      -.36997E+02    -.42253E+03       0.                 0.
  5      -.12357E+03     .56250E+03
  6      -.12357E+03    -.56250E+03
  7      -.10296E+03     .46867E+03
  8      -.10296E+03    -.46867E+03

FILTER NO.: 2   BLOCK NO.:  7   GF= .28254E+02      BW=        .943

              POLES( MHZ*2*PI)                      ZEROS( MHZ*2*PI)
NO.            REAL          IMAG                     REAL          IMAG
  1      -.18817E+01     .15098E+04       0.                 0.
  2      -.18817E+01    -.15098E+04       0.                 0.
  3      -.18770E+01     .15061E+04
  4      -.18770E+01    -.15061E+04

FILTER NO.: 3   BLOCK NO.: 12   GF= .39478E-02      BW=        .006

              POLES( MHZ*2*PI)                      ZEROS( MHZ*2*PI)
NO.            REAL          IMAG                     REAL          IMAG
  1      -.22219E-01     .11312E+03       0.                 0.
  2      -.22219E-01    -.11312E+03       0.                 0.
  3      -.22210E-01     .11308E+03
  4      -.22210E-01    -.11308E+03

GF=FILTER GAIN CONSTANT
BW=FILTER NOISE BANDWIDTH (MHZ)

+++++++++++++++++++++++++++++++++++++++++++++++++++++


FREQUENCY AT CENTER OF LAST IF IS      18.0000 MHZ
 IS DATA CORRECT? ANSWER YES OR NO
?YES
```

Figure 6. Data Printout for Receiver Shown in Figure 5 (Continued)

b) If the block type entered is combiner and another block type is combiner:

* ILLEGAL ENTRY: TWO COMBINERS NOT PERMITTED

The program returns to the start of Section 3.3.1.1. If no other block type is combiner the program advances to block data renumbering Section 3.3.1.2.

c) If the block type entered is neither detector or combiner the program advances to Section 3.3.1.2.

3.3.1.2. Block Data Renumbering -

a) If the receiver blocks include a detector, its block number is advanced by one if the number is greater than I.
b) If the receiver blocks include a combiner, its block number is advanced by one if the number is greater than I.
c) If the block type entered is mixer:
   c.1) Data associated with the receiver frequency plan and spur performance (mixer catalog number, oscillator frequencies and sideband converted) for other mixers have the mixer number advanced by one if the block number is greater than I.
   c.2) New mixer given correct mixer number (the gap in mixer numbers resulting from (c.1) and block number I.
   c.3) The number of mixers is increased by one.
d) If the block type entered is filter:
   d.1) Data associated with filter number (gain constant, pole and zero locations, pole and zero number, noise bandwidth and filter type (fixed or tuned) have the filter number advanced by one if the block number is greater than I.
   d.2) New filter given correct filter number and block number I.
   d.3) The number of filters is increased by one.
   d.4) If the block number, I, is less than the detector block number, the number of predetection filters is increased by one.
   d.5) If the block number, I, is greater than the detector block number, the number of baseband filters is increased by one.
e) Data associated with block sequence (gain, noise figure, intermodulation intercepts and 1db compression level have their block number advanced by one if it is greater than I.
f) The total number of blocks is increased by one.

3.3.1.3 New Block Data Entry - Dependent on the type of the new block, the appropriate sequence of questions are asked in accordance with the flow diagram of Figure 4. When the exit triangle is reached the add-a-block process is complete.

3.3.2 Non-Block-Associated Data Correction

There is only one data parameter not associated with any block - the frequency of the last IF, needed to determine the receiver frequency plan and spur product frequencies. (If there are no mixers the corresponding data parameter is the input filter passband mid-frequency.) The user is asked:

*   CHANGE FREQUENCY OF LAST IF?

If there are no mixers the question is:

*   CHANGE INPUT FILTER PASSBAND MID-FREQUENCY?

If no, the program proceeds to Section 3.3.3.

If yes, the user is requested:

*   ENTER NEW FREQUENCY (MHZ)

The new frequency is entered and the program proceeds to Section 3.3.3.

3.3.3 Block Associated Data Entry

Provision is made to change data for 1 to 6 blocks.

*   HOW MANY BLOCKS HAVE DATA ERRORS? INTEGER ANSWER 1 TO 6

The user enters the number of blocks with data he intends to change.

*   ENTER LIST OF BLOCK NUMBERS REQUIRING DATA CHANGES

*   CAUTION: DO NOT ENTER MORE THAN 6 BLOCK NUMBERS

*   EXAMPLE: 5, 9, 10, 17, 18

The user is asked to enter data in response to the flow diagram questionnaire of Figure 4 for each block to be corrected. The initial question for each block is:

*   INPUT TYPE: BLOCK I

I will be the sequence 5, 9, 10, 17 and 18 (in turn) for the example given. After completion of data entry for each block (when the exit triangle is reached on the flow diagram) the reader is asked:

*   BYPASS DATA PRINTOUT?

If yes, the corrected data is not printed.

If no, the corrected data is printed in accordance with the format of Figure 6 containing those sections of the data printout appropriate to the changes made.

The user is then asked:

*   IS DATA CORRECT?

If the user is satisfied that the changes have been entered correctly and that there are no other changes he wishes to make he will answer affirmatively. If yes, the data is entered into a file for future use. If no, the data correction process is repeated.

3.4 DATA STORAGE

If the response to the question *IS DATA CORRECT? is yes, all of the receiver data is entered into a file and the desired computations indicated by the user in Section 3.1.2 are performed in turn. The user may then make subsequent computations on the same receiver, without reentering the data by responding yes to the question on previous file status of Section 3.1.1. As indicated in Section 3.2.2 he has the option for printout of the stored data. He is also asked: *IS DATA CORRECT? and has the option to correct stored data.

3.5 PRELIMINARY COMPUTATIONS

The number of frequency conversions between the receiver input and each filter and mixer are determined. The center frequency of each filter and the minimum and maximum input and output frequency at each mixer are computed. This information is necessary for computation of receiver performance in the various categories listed in 3.1.2. The following sequence of computations is carried out:

a) Compute minimum and maximum signal input (and output) frequency for each mixer.
b) Compute number (modulo 2) of inversions from receiver input to each mixer output.
c) For each filter search for the number of the preceding and following mixer.
d) Compute (from (b) and (c) the number of inversions from receiver input to each filter.
e) Compute center frequency for each filter (average of minimum and maximum input frequency of following mixer).

If the receiver includes a tuneable filter the user is instructed:

*   RECEIVE PERFORMANCE COMPUTED WITH TUNEABLE FILTERS:
*   SET TO MINIMUM INPUT FREQUENCY (OPTION 1)
*   SET TO MAXIMUM INPUT FREQUENCY (OPTION 2)
*   ENTER OPTION (ANSWER 1 OR 2)

If $\left\{\begin{matrix}1\\2\end{matrix}\right\}$ the tuneable filter parameters for the $\left\{\begin{matrix}\text{minimum}\\\text{maximum}\end{matrix}\right\}$ or $\left\{\begin{matrix}\text{maximum}\\\text{minimum}\end{matrix}\right\}$ tuned frequency are employed dependent on whether the number of mixer inversions prior to the tuneable filter is even or odd.

3.6 FREQUENCY PLAN COMPUTATIONS

If the response to the question in Section 3.1.2 relative to frequency plan computations was no the program advances to Section 3.7.

If yes, the frequency plan block diagram is printed, listing the sequence of mixers and the minimum and maximum frequency at the input and out of each mixer (based on the computations of Section 3.5.a). Also, the minimum and maximum local oscillator frequency for each mixer is printed. A sample printout is given in Figure 7.

3.7 NOISE FIGURE AND SENSITIVITY COMPUTATIONS

3.7.1 Noise Figure Computations

If the response to the question in Section 3.1.2 relative to noise figure computations is no the program advances to Section 3.8.

If yes, and the receiver block diagram includes a combiner, the effective noise figure of the equivalent amplifier is computed and substituted for the noise figure of the combiner block.

```
++++++++++++++ FREQUENCY  PLAN  ++++++++++++++++++++++++

ALL FREQUENCIES GIVEN IN MHZ
                                    !
                                    !
                          69.747    !        100.253
                                    !
                                    !
                                ----------------
                               !                !
                               !                !
                               !     MIXER      !
          310.000-    340.000  !                !
   ---------------------------->!                !
           LOC. OSC.           !       1        !
                               !                !
                               !                !
                                ----------------
                                    !
                                    !
                         239.747    !        240.253
                                    !
                                    !
                                ----------------
                               !                !
                               !                !
                               !     MIXER      !
          221.750-    222.250  !                !
   ---------------------------->!                !
           LOC. OSC.           !       2        !
                               !                !
                               !                !
                                ----------------
                                    !
                                    !
                          17.997    !        18.003
                                    !
                                    !
```

Figure 7. Frequency Plan Printout

Define G_i, F_i as the gain and noise figure of block i.

Define $G_{i,j}$, $F_{i,j}$ as the gain and noise figure of the cascade of blocks from block i through block j.

The receiver has N blocks. If the receiver block diagram includes a detector in block $(M+1) \leq N$, noise figure computations are made for the cascade of blocks 1 through M, based on iterated use of the noise figure cascade algorithm. If there is no detector the computation is made for blocks 1 through N.

$$F_{i,M} = F_i + (F_{(i+1),M} - 1)/G_i \qquad (3)$$

Since $F_{M,M} = F_M$ is known, the noise figures, $F_{i,M}$, are determined in decending sequence from (3) starting at i - M - 1

$$F_{i,(i+1)} = F_{1,i} + (F_{(i+1)} - 1)G_{1,i} \qquad (4)$$

Since $F_{1,1} = F_1$ is known, the noise figures, $F_{1,i}$, are determined in succession from (3.7.2) starting at i = 2

The successive values of $F_{1,i}$ and $F_{i,M}$ are tabulated in the printout (a sample printout is shown in Figure 8.

If it is desired to determine $F_{i,j}$ from the tabulated values of Figure 8. proceed as follows:

a) Convert the tabulated values $F_{1,j}$ and $F_{1,(i-1)}$ from decibels to power ratios.

b) Convert the cumulative power gain $G_{1,(i-1)}$ from decibels to power ratios. **NOTE:** The cumulative power gain $G_{1,i}$ is tabulated for each i in the dynamic range performance printout discussed in Section 3.8

Since:

$$F_{1,j} = F_{1,(i-1)} + (F_{i,j} - 1)/G_{1,(i-1)}$$

$$F_{i,j} = 1 + G_{1,(i-1)} (F_{1,j} - F_{1,(i-1)}) \qquad (5)$$

c) Compute $F_{i,j}$ from (5)

d) Convert $F_{i,j}$ from power ratio to decibels.

3.7.2 Sensitivity Computations

A set of cascaded blocks with noise bandwidth B_N will yeild a prescribed output signal to noise ratio (P_o/P_N) with an input signal level given by

$$P_S = (P_o/P_N) \cdot F.KT.B_N \qquad (6)$$

F is determined for blocks i through M and 1 through i by (3) and (4) for all I. B_N is determined for any set of blocks by the network functions of the filters included in the set of blocks. For two such filters with network functions $H_1(S)$ and $H_2(S)$, the composite network function $H(S) = H_1(S).H_2(S)$

++++++++++++++ NOISE FIGURE PERFORMANCE ++++++++++++

	MAXIMUM GAIN				MINIMUM GAIN			
BLOCK	FTOT	SEN	F(I)	SN(I)	FTOT	SEN	F(I)	SN(I)
1	0.0	-88.0	9.6	-116.7	0.0	-88.0	12.8	-113.5
2	5.5	-82.5	9.6	-116.7	5.5	-82.5	12.8	-113.5
3	5.8	-82.2	17.5	-108.7	5.8	-82.2	21.9	-104.3
4	6.6	-81.4	27.2	-99.0	6.6	-81.4	31.8	-94.4
5	8.2	-79.8	8.2	-118.0	8.2	-79.8	12.8	-113.4
6	8.4	-79.5	15.0	-111.2	8.4	-79.5	21.9	-104.3
7	8.4	-95.8	7.5	-118.7	8.4	-95.8	14.4	-111.8
8	8.4	-95.8	7.5	-118.7	8.4	-95.8	14.4	-111.8
9	9.1	-95.2	7.5	-118.7	9.1	-95.2	14.4	-111.8
10	9.1	-95.2	13.3	-112.9	9.1	-95.2	23.8	-102.4
11	9.2	-95.1	13.3	-112.9	9.2	-95.1	23.8	-102.4
12	9.2	-117.0	5.8	-120.4	9.2	-117.0	16.3	-109.9
13	9.5	-116.7	5.8	X	9.5	-116.7	16.3	X
14	9.5	-116.7	5.8	X	9.9	-116.3	26.0	X
15	9.6	-116.7	5.8	X	10.7	-115.5	11.0	X
16	9.6	-116.7	5.8	X	10.8	-115.4	19.6	X
17	9.6	-116.7	5.8	X	10.8	-115.4	29.4	X
18	9.6	-116.7	5.8	X	11.1	-115.2	39.4	X
19	9.6	-116.7	5.8	X	11.7	-114.5	9.4	X
20	9.6	-116.7	5.8	X	11.8	-114.5	17.2	X
21	9.6	-116.7	5.8	X	11.8	-114.5	26.9	X
22	9.6	-116.7	5.8	X	12.0	-114.2	36.8	X
23	9.6	-116.7	5.8	X	12.5	-113.7	6.8	X
24	9.6	-116.7	5.8	X	12.6	-113.7	11.4	X
25	9.6	-116.7	5.5	X	12.6	-113.7	20.1	X
26	9.6	-116.7	0.0	X	12.8	-113.5	30.0	X

I=BLOCK NUMBER
FTOT=NOISE FIGURE(DB),FIRST I BLOCKS
SEN=SENSITIVITY(DBM),FIRST I BLOCKS,(S/N=10DB)
F(I)=NOISE FIGURE (DB) LOOKING INTO BLOCK I
SN(I)=SENSITIVITY(DBM)LOOKING INTO BLOCK I(S/N=10 DB)

Figure 8. Noise Figure Performance Printout

Figure 9 plots $|H_1(j\omega)|^2/|H_1(j\omega_o)|^2$; $|H_2(j\omega)|^2/|H_2(j\omega_o)|^2$ and $|H(j\omega)|^2/|H(j\omega_o)|^2 = |H_1(j\omega)|^2|H_2(j\omega)|^2/|H_1(j\omega_o)|^2|H_2(j\omega_o)|^2$ vs. ω, where ω_o is the common †resonance frequency. It is noted that:

a) B_N for cascaded filters cannot exceed the noise bandwidths of the separate filters.

b) If $B_{N1} >> B_{N2}$, $B_N \approx B_{N2}$

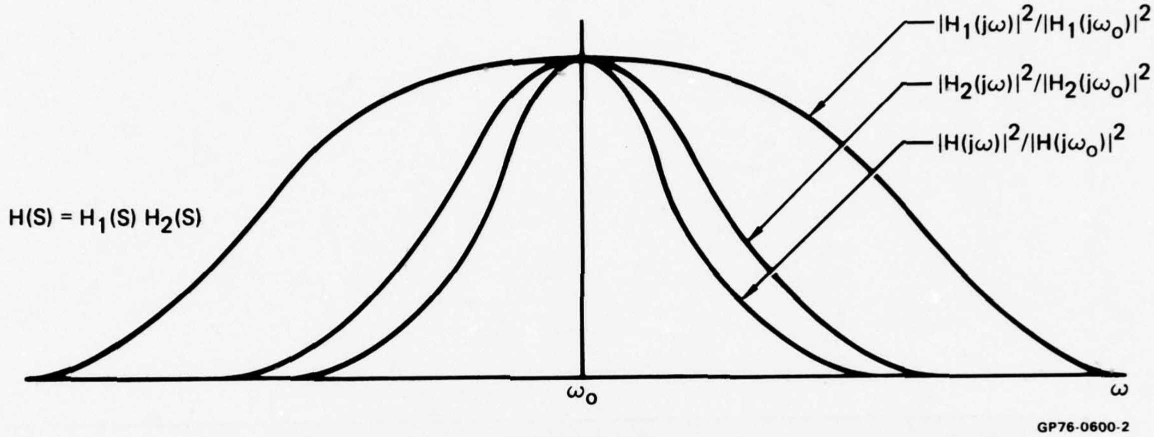

Figure 9. Relative Magnitude Squared Functions for Cascaded Filters

The different filters in a receiver will ordinarily differ markedly in noise bandwidth so that the noise bandwidth of a number of cascaded filters will approximate that of the filter with the smallest noise bandwidth.

A search is made for the narrowest filter in each set of blocks i through M and 1 through I for all I and their noise bandwidths are substituted into (6). (P_o/P_N) is taken as 10 (corresponding to 10 decibels) and KT = $4(10^{-21})$ watts/Hz. The sensitivities $P_{si,M}$ and $P_{s1,i}$ are computed from (6) and their values are printed, together with $F_{1,i}$ and $F_{i,M}$, for each i in Figure (7). For sets of blocks without a specified noise bandwidth, sensitivity computations are omitted from the printout.

3.7.3 Variable Gain Receivers

The noise figures for block sets i through M and 1 through i computed in equations (3) and (4) are gain dependent. Parallel computations are made with all variable gain blocks set to minimum and maximum gains.

3.8 DYNAMIC RANGE COMPUTATIONS

If the response to the question in Section 3.1.2 relative to dynamic range computations is no the program advances to Section 3.9.

If yes, the block gain distribution is checked to determine which block will attain its 1db compression level with the minimum input signal. Also, the overload signal is determined. This is accomplished by the following sequence of computations:

† Taking into account frequency translations due to mixers.

a) The relative margin, M_i (in decibels), for each block for which a 1db compression level has been specified is computed as $M_i = X_i - [G_{1,(i-1)}]_{db}$; where X_i is the 1db compression level for block i in dbm, and $G_{1,(i-1)_{db}}$ is the gain of the block set 1 through i - 1 expressed in decibels. (NOTE: $G_{1,i}$ is determined for all i as part of the noise figure computations (Section 3.7) and used to compute $F_{1,(i+1)}$ by means of equation (4).

b) The minimum value of the M_i is determined.

c) For each block, $G_{1,(i-1)\,db}$ and $M_i - (M_i)_{Min}$ are printed in accordance with the sample printout of Figure 7. If X_i is unspecified for any block, no computation or printout is made for $M_i - (M_i)_{Min}$

d) The minimum signal level that overloads at least one block is obtained by subtracting $G_{1,(i-1)\,db}$ from X_i for the block(s), i, for which $M_i = (M_i)_{Min}$

e) Parallel computations and printouts are made for the cases where variable gain blocks are all set to their minimum and maximum values. A sample printout is given in Figure 10.

NOTE: The printout of $G_{1,i\,db}$ for each i is used to compute $F_{i,j}$, the noise figure for the block set from block i through block j, in accordance with the discussion of Section 3.7.1.

NOTE: For receivers that include a combiner block, the precombiner gains and noise figures for the "undesired" inputs may be obtained by running the signal path program off-line to model the pre-combiner receiver section. The user should respond yes to the questions in Section 3.1.2 related to noise figure and dynamic range computation and no to the remaining questions. The printouts will provide the required parameters. Variations between "undesired" input block sets can be accommodated by re-running the program in accordance with the discussion of Section 3.14 and using the data correction options discussed in Section 3.3.3.

3.9 THIRD ORDER INTERMODULATION

3.9.1 Third Order Intercept Computations

Third order intermodulation is a measure of the non-linearities experienced by the modulated signal in its transmission through the receiver. All non-linear stages contribute to this in-band process.

++++++++++++++++++++ DYNAMIC RANGE ++++++++++++++++++

BLK	MAXIMUM GAIN G(I)	MAXIMUM GAIN MARGIN	MINIMUM GAIN G(I)	MINIMUM GAIN MARGIN
1	0.0		0.0	
2	0.0	96.0	0.0	21.0
3	10.0	86.0	10.0	11.0
4	20.0		20.0	
5	1.0	95.0	1.0	20.0
6	11.0	112.0	11.0	37.0
7	3.5		3.5	
8	3.5		3.5	
9	3.5	92.5	3.5	17.5
10	13.5		13.5	
11	13.5	109.5	13.5	34.5
12	6.0		6.0	
13	6.0	90.0	6.0	15.0
14	16.0		16.0	
15	16.0	80.0	1.0	20.0
16	26.0	70.0	11.0	10.0
17	36.0	60.0	21.0	0.0
18	46.0		31.0	
19	46.0	50.0	1.0	20.0
20	56.0	40.0	11.0	10.0
21	66.0	30.0	21.0	0.0
22	76.0		31.0	
23	76.0	20.0	1.0	20.0
24	86.0	10.0	11.0	10.0
25	96.0	0.0	21.0	0.0
26	106.0		31.0	

OVERLOAD SIGNAL -103.0   OVERLOAD SIGNAL -28.0

G(I)=CUMULATIVE GAIN TO INPUT TO BLOCK I
OVERLOAD SIGNAL(DBM) IS RECEIVER INPUT SIGNAL LEVEL
THAT CAUSES AT LEAST ONE BLOCK TO ATTAIN ITS
1 DB COMPRESSION LEVEL

MARGIN=DIFFERANCE IN DB BETWEEN BLOCK I 1 DB
COMPRESSION LEVEL AND INPUT TO BLOCK I
CORRESPONDING TO OVERLOAD SIGNAL

IF MARGIN COLUMN IS BLANK, BLOCK I DOES NOT OVERLOAD

```
OPTIONS AVAILABLE TO COMPUTE:
THIRD ORDER INTERMOD ONLY(OPTION 1)
SECOND ORDER INTERMOD ONLY(OPTION 2)
BOTH THIRD AND SECOND ORDER INTERMOD(OPTION 3)
ENTER OPTION 1,2,OR 3
?3
```

Figure 10. Dynamic Range Printout

If the response to the question in Section 3.1.2 relative to intermod computations is no the program advances to Section 3.11.

If yes the user is advised:

* OPTIONS AVAILABLE TO COMPUTE:
* THIRD ORDER INTERMOD ONLY (OPTION 1)
* SECOND ORDER INTERMOD ONLY (OPTION 2)
* BOTH THIRD AND SECOND ORDER INTERMODE (OPTION 3)
* ENTER OPTION 1, 2 OR 3

If the answer is 2 the program advances to Section 3.10.

If 1 or 3, the third order intercept, ${}_3P_{i,j}$, for the block set i through j is computed for the block sets i through M and 1 through i (i=1,2 M), based on iterated use of the intermodulation intercept cascade algorithm:

$${}_3P^{-1}_{1,(i+1)} = {}_3P^{-1}_{1,i} + G_{1,i} \cdot {}_3P^{-1}_{(i+1),M} \tag{7}$$

and

$${}_3P^{-1}_{1,(i+1)} = {}_3P^{-1}_{1,i} + G_{1,i} \cdot {}_3P^{-1}_{(i+1)} \tag{8}$$

where ${}_3P_i$ is the third order intercept of block i. The successive values of ${}_3P_{1,i}$ and ${}_3P_{i,M}$, (expressed in dbm) are tabulated in the printout (in accordance with the sample of Figure 11).

If it is desired to determine ${}_3P_{i,j}$ from the tabulated values of Figure 3-8 proceed as follows:

a) Convert the tabulated values of ${}_3P_{1,(i-1)}$ and ${}_3P_{1,j}$ from dbm to milliwatts.

b) Convert the cumulative power gain $G_{1,(i-1)}$ from decibels to power ratios (see step (b) of procedure for computing $F_{i,j}$ in Section 3.7.1)

Since:

$${}_3P^{-1}_{1,j} = {}_3P^{-1}_{1,(i-1)} + G_{1,(i-1)} \cdot {}_3P^{-1}_{i,j}$$

$${}_3P^{-1}_{i,j} = ({}_3P^{-1}_{1,j} - {}_3P^{-1}_{1,(i-1)}) / G_{1,(i-1)} \tag{9}$$

c) Compute ${}_3P_{i,j}$ (in millwatts) from (3.9.3)

d) Convert ${}_3P_{i,j}$ from milliwatts to dbm.

3.9.2 Intermodulation Computations

The signal level (in dbm) for the two intermodulating sinusoids to yield third order intermoduation products equal to the noise level in a block set from i through j is:

$$[P_{i,j}]_{db} = ([P_N]_{db} + 2\,[{}_3P_{i,j}]_{db})/3 \tag{10a}$$

where:

$$P_N = F_{i,j} \,.\, KT \,.\, B_{Ni,j} \tag{10b}$$

and where $B_{Ni,j}$ is the noise bandwidth for the block set i through j as computed in Section 3.7.2.

++++++++++++ INTERMODULATION PERFORMANCE ++++

THIRD ORDER INTERMOD

I	MAXIMUM GAIN PTOT	Q	P(I)	Q(I)	MINIMUM GAIN PTOT	Q	P(I)	Q(I)
1	999.0	999.0	-88.5	-101.2	999.0	999.0	-18.4	-53.4
2	8.0	-25.5	-88.5	-101.2	8.0	-25.5	-18.4	-53.4
3	-2.4	-32.3	-78.5	-91.9	-2.4	-32.3	-8.4	-43.7
4	-2.4	-32.1	-68.5	-82.0	-2.4	-32.1	1.7	-33.7
5	-2.9	-31.8	-87.5	-101.0	-2.9	-31.8	-17.3	-52.7
6	-2.9	-31.8	-77.5	-92.0	-2.9	-31.8	-7.3	-43.0
7	-2.9	-37.2	-85.0	-99.5	-2.9	-37.2	-14.8	-50.5
8	-2.9	-37.2	-85.0	-99.5	-2.9	-37.2	-14.8	-50.5
9	-3.6	-37.5	-85.0	-99.5	-3.6	-37.5	-14.8	-50.5
10	-3.6	-37.5	-75.0	-90.9	-3.6	-37.5	-4.8	-40.6
11	-3.7	-37.5	-75.0	-90.9	-3.7	-37.5	-4.8	-40.6
12	-3.7	-44.8	-82.5	-98.4	-3.7	-44.8	-12.3	-48.1
13	-4.7	-45.4	-82.5	X	-4.7	-45.4	-12.3	X
14	-4.7	-45.4	-72.5	X	-4.7	-45.2	-2.2	X
15	-9.7	-48.7	-72.5	X	-5.0	-45.2	-17.2	X
16	-18.6	-54.6	-62.5	X	-7.1	-46.6	-7.2	X
17	-28.5	-61.2	-52.5	X	-14.0	-51.1	2.9	X
18	-28.5	-61.2	-42.5	X	-14.0	-51.0	14.5	X
19	-38.5	-67.9	-42.5	X	-14.0	-50.9	-15.5	X
20	-48.5	-74.5	-32.5	X	-14.4	-51.1	-5.4	X
21	-58.5	-81.2	-22.5	X	-16.7	-52.6	4.8	X
22	-58.5	-81.2	-12.5	X	-16.7	-52.6	17.5	X
23	-68.5	-87.9	-12.5	X	-16.8	-52.4	-12.5	X
24	-78.5	-94.5	-2.4	X	-16.9	-52.5	-2.4	X
25	-88.5	-101.2	8.0	X	-18.4	-53.5	8.0	X
26	-88.5	-101.2	999.0	X	-18.4	-53.4	999.0	X

Figure 11. Third Order Intermod Printout

$P_{i,M}$ and $P_{1,i}$ are computed for each i from (10) and tabulated in the printout of Figure 11. Parallel computations and printouts are made for the maximum and minimum gain conditions.

3.10 FRONT END SECOND ORDER INTERMODULATION

3.10.1 Second Order Intercept Computations

Receiver front end second order intermodulation performance is a measure of its vulnerability to strong interfering signals. The block set consisting of the first block through the first mixer block is relatively wide-band compared to the rest of the receiver so that pairs of strong interfering signals can generate intermodulation products in the passband of the section of the receiver following the first mexer (the first i.f).

Attempts to minimize the problem involve minimization of second order non-linearity of the front end stages and use of front end filtering. Accordingly, evaluation of second order intermodulation performance requires computation of second order intermodulation intercepts for cascaded quasi-linear networks with memory.

If the option chosen in Section 3.9 is 1 the program advances to Section 3.11.

If the option chosen is 2 or 3, the user is requested:

* ENTER 2 RECEIVER INPUT FREQUENCIES

The second order intercept, ${}_2P_{i,j}$, for the block set i through j, is computed for the sets i through M and 1 through i (where M is the number of the first mixer block; i=1,2...M) based on iterated use of:

$$ {}_2P^{-1}_{i,M} = {}_2P^{-1}_{i} + G_i \cdot {}_2P^{-1}_{(i+1),M} \qquad (11)$$

$$ {}_2P^{-1}_{1,(i+1)} = {}_2P^{-1}_{1,i} + G_{1,i} \cdot {}_2P^{-1}_{(i+1)} \qquad (12)$$

If block is a filter, the value employed for $G_{i\ db}$ is half the sum of the filter attenuations for the two frequencies entered. If the block set 1 through i includes one or more filters, the value employed for $G_{1,i\ db}$ is the cumulative sum of the block gains, (where, for each filter the average of the filter attenuations for the two frequencies is taken as the block gain).

With these modifications, the second order intercept is computed for each block i and tabulated in the printout of Figure 12. The printout is in the same format as employed for third order intermodulation as shown in Figure 11.

3.10.2 Intermodulation Computations

The signal level, in (dbm) for two intermodulating sinsuoids at the frequencies entered, to yield a second order product equal to the noise level, in a block set from i through j is:

$$ P_{i,j\ db} = ([P_N]_{db} + [{}_2P_{i,j}]_{db})/2 \qquad (13)$$

FRONT END SECOND ORDER INTERMOD

ENTER 2 RECEIVER INPUT FREQUENCIES(MHZ)
?55.,125.

	MAXIMUM GAIN				MINIMUM GAIN			
I	PTOT	Q	P(I)	Q(I)	PTOT	Q	P(I)	Q(I)
1	999.0	999.0	30.6	-48.0	999.0	999.0	30.6	-46.4
2	41.6	-25.4	9.9	-58.4	41.6	-25.4	9.9	-56.8
3	31.2	-30.5	20.3	-49.2	31.2	-30.5	20.3	-47.0
4	31.2	-30.1	38.5	-35.2	31.2	-30.1	38.5	-32.9
5	30.8	-29.5	19.5	-54.2	30.8	-29.5	19.5	-51.9
6	30.6	-29.5	35.0	-43.1	30.6	-29.5	35.0	-39.7

I=BLOCK NUMBER
PTOT=INTERMOD INTERCEPT(DBM),FIRST I BLOCKS
Q=TWO TONE SIGNAL LEVEL(DBM),FIRST I BLOCKS
(INTERMOD LEVEL=NOISE LEVEL)
P(I)=INTERMOD INTERCEPT(DBM) LOOKING INTO BLOCK I
Q(I)=TWO TONE SIGNAL LEVEL(DBM) INTO BLOCK I
(INTERMOD LEVEL=NOISE LEVEL)

Figure 12. Front End Second Order Intermod Printout

where P_N is the value computed in the third order case, equation (10b).

$P_{i,M}$ and $P_{1.i}$ (where M is the mixer block number and i=1,2...M) are computed from (13) and tabulated in the printout of Figure 12. The printout format is similar to that for the third order intermodulation (Figure 11) Parallel computations and printouts are made for maximum and minimum gain conditions.

3.11 SPURIOUS RESPONSE PERFORMANCE COMPUTATIONS

If the response to the question in Section 3.1.2 relative to spur performance computations is <u>no</u> the program advances to Section 3.12.
If <u>yes</u> the following sequence of computations is executed:

a) For each mixer, in turn, starting from the receiver input, with lowest and highest output frequencies, ω_{IL} and ω_{IH}, determined during preliminary computations (Section 3.5) and given minimum and maximum oscillator frequency, ω_{oL} and ω_{oH}, four frequencies are determined for each j,k pair of mixer products:

$$
\begin{aligned}
\omega_1 &= (k\omega_{oL} - \omega_{IH})/j \\
\omega_2 &= (k\omega_{oL} - \omega_{IL})/j \\
\omega_3 &= (k\omega_{oH} = \omega_{IL})/j \\
\omega_4 &= (k\omega_{oH} - \omega_{IH})/j
\end{aligned}
\qquad (14)
$$

NOTE: ω_1 to ω_2 and ω_3 to ω_4 represents the ranges of frequencies at the mixer input that can generate a j,k spurious product in the band ω_{IL} to ω_{IH}.

b) A comparison is made of ω_1 to ω_2 and ω_3 to ω_4 with the input signal band (computed in Section 3.5 and printed in Section 3.6).

b.1) If there is an overlap, the spur will not be benefitted by filtering in the overlap band. The worst case frequency is chosen (arbitrarily) as the center of the overlap band.

c.1) The local oscillator frequency at the mixer corresponding to the worst case frequency is determined by an interpolation process (the worst case frequency is related to the band of input frequencies ω_1 to ω_2 or ω_3 to ω_4 as its corresponding oscillator frequency is related to the band ω_{oL} to ω_{oH}).

d.1) Local oscillators of preceding mixers are set to the mid-point of their frequency ranges.

e.1) The frequency offset of the worst case spur frequency at the receiver input is equal in magnitude to the worst case spur frequency offset at the input to the generating mixer.

b.2) If $\omega_1 > \omega_{sH}$, the worst case spur frequency at the mixer input is ω_1 and the offset is $\delta = \omega_1 - (\omega_{sL} + \omega_{sH})/2$ relative to the center of the mixer input passband. NOTE: $\delta > 0$

c.2) The local oscillator at the generating mixer is ω_{oL} for the worst case spur.

d.2) Local oscillators of preceding mixers are set to their maximum or minimum frequency dependent on the number of inversions between any preceding mixer and the generating mixer. With each preceding mixer (progressing toward the receiver input) the magnitude of the frequency offset is reduced by half the difference between maximum and minimum frequency for the oscillator applied to the preceding mixer. If the frequency offset, at a given preceding mixer output is less than half its output passband, the given mixer and all other mixers (progressing toward the receiver input) are set to their mid frequency.

e.2) The frequency offset magnitude of all mixers with oscillators set to mid-frequency is maintained to the receiver front end and the worst case input frequency is dependent on the sequence of mixer inversions.

f.2) With the worst case frequency offset determined throughout the receiver (prior to the generating mixer), the attenuation provided by each filter is computed and added. (NOTE: Filters preceding or following mixers with local oscillators set to mid-frequency in accordance with (e.2) are assumed to provide no filtering).

b.3) If $\omega_4 < \omega_{sL}$, the worst case spur offset is $\delta = \omega_4 - (\omega_{sL} + \omega_{sH})/2 < 0$. Similar computations are made as for the case (b.2) (with reverse choice of mixer local oscillator frequencies).

b.4) If $\omega_2 < \omega_{sL} < \omega_{sH} < \omega_3$, parallel computations are made, based on offsets $\delta_A = \omega_2 - (\omega_{sL} + \omega_{sH})/2 < 0$ and $\delta_B = \omega_3 - (\omega_{sL} + \omega_{sH})/2 > 0$, to determine mixer local oscillator frequency settings, worst case input frequency and filtering to the worst case frequency. The frequency, ω_2 or ω_3, providing the least total filtering is selected as the worst case frequency.

For a receiver with noise Figure F and noise bandwidth B_N, the input noise power is $P_N = FKTB_N$. If G is the gain prior to the mixer and L_c the mixer conversion loss (both expressed in db), the noise power at the mixer output is $[P_N]_{dbm} + G - L_c$. If the j,k spur product output is equal to the noise power level:

$$[P_N]_{dbm} + G - L_c = P_a - L_c - R_{j,k} \qquad (15)$$

where $R_{j,k}$ represents the difference (in decibels) between the signal level and the j,k product level when P_a (expressed in dbm) is applied to the mixer input.

The corresponding level at the receiver input (in dbm) is

$$X = P_a - G \qquad (16)$$

The j,k spur product intercept, $P_{j,k}$, is related to $R_{j,k}$ and P_a by:

$$P_{j,k} = P_a + R_{j,k}/(j-1) \qquad (17)$$

Combining equations (15), (16), and (17) and solving for X: ng

$$X = [(j-1)\ (P_{j,k} - G) + [P_N]_{dbm}]\ /j \qquad (18)$$

c) The input spur signal level required to yield an output spur product equal to the noise level (if there were no receiver filtering) is determined, for each mixer and all spur products, from (18). The worst case j,k spur product (with filtering) is obtained by adding the computed worst case filtering to X.

d) The spur response performance is tabulated in **Figure 13 providing,** for each mixer and all spur products:

1) X (input spur signal level where mixer output spur level equals noise level). (Labeled QM in printout)
2) Worst case frequency for each spur product j,k.
3) Local oscillator frequency for each mixer to yield the worst case spur frequency.
4) Composite filtering to worst case spur frequency. (Labeled QF)

3.12 WAVEFORM PERFORMANCE

If the response to the question in Section 3.1.2 relative to signal waveform is <u>no</u> the program advances to Section 3.13.

If <u>yes,</u> the receiver output waveform is computed, as follows:

a) The network function for each filter is separated into partial fractions and the coefficients determined.

b) The receiver input function is defined as a piecewise combination of as many as six segments, each defined by the amplitude and phase of a modulation time function.

The user is requested:

* ENTER NUMBER OF SEGMENTS (1 to 6) FORMING INPUT SIGNAL
* MODULATION FUNCTION

The user responds with an integer, <u>M</u>, whereupon, for each segment, M ($1 \leq N \leq M$), in turn, the user is requested:

* FOR SEGMENT N ENTER SEGMENT TIME DURATION

Three function types are available to describe the amplitude and phase modulation function by choice of the arbitrary constants, k_i. The user is advised:

* FUNCTION DESCRIPTORS ARE: EXPONENTIAL, SINUSOIDAL, PARABOLIC
* FOR SEGMENT N ENTER AMPLITUDE FUNCTION DESCRIPTOR

If the response is <u>exponential</u>, the defining equation for the arbitrary constants is printed:

* F = K1 + K2*EXP(K3*T)

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1

3	1	-36.6	171.8	229.9	80.1	0.0	3	1
3	2	-34.9	132.9	155.8	154.2	0.0	3	1
3	3	-41.2	58.2	96.7	228.3	0.0	3	2
3	4	-32.2	109.8	50.3	289.7	0.0	1	3
3	5	-42.2	163.0	23.6	363.6	0.0	1	3
3	6	-33.2	102.3	97.5	437.5	0.0	1	3
3	7	-43.2	148.9	171.4	511.4	0.0	1	3
3	8	-33.2	170.0	245.3	585.3	0.0	1	3
4	0	-27.8	236.0	305.5	4.5	0.0	3	1
4	1	-26.8	181.4	249.9	60.1	0.0	3	1
4	2	-27.8	154.9	194.4	115.6	0.0	3	1
4	3	-27.3	120.0	138.8	171.2	0.0	3	1
4	4	-27.3	60.3	98.2	226.8	0.0	3	2
4	5	-28.1	76.5	67.3	272.7	0.0	1	3
4	6	-27.8	183.9	11.9	328.1	0.0	1	3
4	7	-28.1	135.8	43.6	383.6	0.0	1	3
4	8	-26.8	102.4	99.0	439.0	0.0	1	3
5	0	-26.1	240.0	306.4	3.6	0.0	3	1
5	1	-28.1	187.8	261.9	48.1	0.0	3	1
5	2	-26.1	166.0	217.5	92.5	0.0	3	1
5	3	-30.0	143.5	173.0	137.0	0.0	3	1
5	4	-26.1	110.6	128.6	181.4	0.0	3	1
5	5	-30.5	61.5	99.1	225.9	0.0	3	2
5	6	-26.1	68.3	77.5	262.5	0.0	1	3
5	7	-31.2	138.7	33.2	306.8	0.0	1	3
5	8	-26.5	189.5	11.2	351.2	0.0	1	3
6	0	-25.7	243.2	307.0	3.0	0.0	3	1
6	1	-25.7	192.4	270.0	40.0	0.0	3	1
6	2	-25.7	173.2	232.9	77.1	0.0	3	1
6	3	-25.7	155.6	195.9	114.1	0.0	3	1
6	4	-25.7	134.8	158.8	151.2	0.0	3	1
6	5	-25.7	103.2	121.8	188.2	0.0	3	1
6	6	-25.7	62.3	99.7	225.3	0.0	3	2
6	7	-25.7	62.3	84.3	255.7	0.0	1	3
6	8	-25.7	115.1	47.3	292.7	0.0	1	3
7	0	-25.4	246.0	307.4	2.6	0.0	3	1
7	1	-25.4	196.1	275.7	34.3	0.0	3	1
7	2	-25.4	178.5	243.9	66.1	0.0	3	1
7	3	-25.4	163.5	212.2	97.8	0.0	3	1
7	4	-25.4	147.6	180.4	129.6	0.0	3	1
7	5	-25.4	127.8	148.7	161.3	0.0	3	1
7	6	-25.4	97.2	116.9	193.1	0.0	3	1
7	7	-25.4	62.8	85.2	224.8	0.0	3	1
7	8	-25.4	56.0	74.1	250.9	0.0	1	2

J=SIGNAL FREQUENCY MULTIPLE
K=OSCILLATOR FREQUENCY MULTIPLE
FWM=WORST CASE SPUR FREQUENCY (MHZ) AT MIXER
FWI=WORST CASE SPUR FREQUENCY (MHZ) AT RECEIVER INPUT

QF=RECEIVER FILTERING(DB) FOR SPUR AT FREQUENCY FWI
IF QF=0, FWM IS IN SIGNAL BAND

QM=INPUT SPUR LEVEL(DBM)(RESPONSE=REC. NOISE LEVEL)
(ASSUMING NO RECEIVER FILTERING)
QM+QF=INPUT SPUR LEVEL(DBM)(RESPONSE=REC. NOISE LEVEL)
INCLUDES RECEIVER FILTERING

OSCILLATOR FREQUENCY CODE FOR WORST CASE SPUR RESPONSE
(INTEGER COLUMN HEADINGS REFER TO MIXER NUMBER)
CODE 3: SET OSCILLATOR TO MAXIMUM FREQUENCY
CODE 2: SET OSCILLATOR TO MID FREQUENCY
CODE 1: SET OSCILLATOR TO MINIMUM FREQUENCY
CODE 0: SET OSCILLATOR TO FREQUENCY GIVEN IN COL. FO

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3	7	-41.6	96.8	643.2	643.2	0.0	1
3	8	-31.6	102.1	746.6	746.6	0.0	1
4	0	-25.9	13.1	60.1	60.1	0.0	3
4	1	-24.9	65.1	25.1	25.1	0.0	3
4	2	-25.9	0.0	97.6	97.6	315.3	0
4	3	-25.4	42.3	172.4	172.4	0.0	1
4	4	-25.4	60.4	249.9	249.9	0.0	1
4	5	-26.2	71.6	327.4	327.4	0.0	1
4	6	-25.9	79.8	404.9	404.9	0.0	1
4	7	-26.2	86.3	482.4	482.4	0.0	1
4	8	-24.9	91.8	559.9	559.9	0.0	1
5	0	-24.1	31.9	48.1	48.1	0.0	3
5	1	-26.1	74.1	20.1	20.1	0.0	3
5	2	-24.1	0.0	82.0	82.0	325.0	0
5	3	-28.0	27.9	137.9	137.9	0.0	1
5	4	-24.1	50.1	199.9	199.9	0.0	1
5	5	-28.5	62.4	261.9	261.9	0.0	1
5	6	-24.1	71.1	323.9	323.9	0.0	1
5	7	-29.2	77.9	385.9	385.9	0.0	1
5	8	-24.5	83.6	447.9	447.9	0.0	1
6	0	-23.6	43.1	40.0	40.0	0.0	3
6	1	-23.6	0.0	94.2	94.2	325.0	0
6	2	-23.6	0.0	71.6	71.6	334.6	0
6	3	-23.6	11.6	115.0	115.0	0.0	1
6	4	-23.6	40.3	166.6	166.6	0.0	1
6	5	-23.6	54.3	218.3	218.3	0.0	1
6	6	-23.6	63.7	270.0	270.0	0.0	1
6	7	-23.6	70.8	321.6	321.6	0.0	1
6	8	-23.6	76.7	373.3	373.3	0.0	1
7	0	-23.2	51.1	34.3	34.3	0.0	3
7	1	-23.2	0.0	80.7	80.7	325.0	0
7	2	-23.2	8.2	62.9	62.9	0.0	3
7	3	-23.2	0.0	99.4	99.4	312.0	0
7	4	-23.2	30.5	142.8	142.8	0.0	1
7	5	-23.2	46.7	187.1	187.1	0.0	1
7	6	-23.2	57.0	231.4	231.4	0.0	1
7	7	-23.2	64.6	275.7	275.7	0.0	1
7	8	-23.2	70.6	320.0	320.0	0.0	1

MIXER NUMBER 2

J	K	QM	QF	FWI	FWM	FO	2	1
1	0	-102.7	210.0	292.0	18.0	0.0	3	1
1	1	-126.7	81.8	105.7	204.3	0.0	3	1
1	2	-91.7	101.4	85.5	425.5	0.0	1	3
1	3	-113.7	181.8	307.2	647.2	0.0	1	3
1	4	-86.7	208.8	529.0	869.0	0.0	1	3
1	5	-102.7	225.9	750.7	1090.7	0.0	1	3
1	6	-81.7	238.5	972.5	1312.5	0.0	1	3
1	7	-98.7	248.6	1194.2	1534.2	0.0	1	3
1	8	-77.7	257.0	1416.0	1756.0	0.0	1	3
2	0	-38.6	223.3	301.0	9.0	0.0	3	1
2	1	-38.6	152.6	189.9	120.1	0.0	3	1
2	2	-38.1	52.9	93.7	231.3	0.0	3	2
2	3	-40.1	171.2	16.4	323.6	0.0	1	3
2	4	-39.6	102.1	94.5	434.5	0.0	1	3
2	5	-43.1	160.0	205.4	545.4	0.0	1	3
2	6	-40.6	183.3	316.2	656.2	0.0	1	3
2	7	-43.1	198.3	427.1	767.1	0.0	1	3
2	8	-40.6	209.6	538.0	878.0	0.0	1	3
3	0	-35.6	230.8	304.0	6.0	0.0	3	1
3	1	-36.6	171.8	229.9	80.1	0.0	3	1
3	2	-34.9	132.9	155.8	154.2	0.0	3	1
3	3	-41.2	58.2	96.7	228.3	0.0	3	2
3	4	-32.2	109.8	50.3	289.7	0.0	1	3
3	5	-42.2	163.0	23.6	363.6	0.0	1	3
3	6	-33.2	102.3	97.5	437.5	0.0	1	3
3	7	-43.2	148.9	171.4	511.4	0.0	1	3
3	8	-33.2	170.0	245.3	585.3	0.0	1	3
4	0	-27.8	236.0	305.5	4.5	0.0	3	1
4	1	-26.8	181.4	249.9	60.1	0.0	3	1
4	2	-27.8	154.9	194.4	115.6	0.0	3	1
4	3	-27.3	120.0	138.8	171.2	0.0	3	1
4	4	-27.3	60.3	98.2	226.8	0.0	3	2
4	5	-28.1	76.5	67.3	272.7	0.0	1	3
4	6	-27.8	183.9	11.9	328.1	0.0	1	3

- 2

++++++ SPURIOUS RESPONSE PERFORMANCE ++++++

MIXER NUMBER 1

J	K	QM	OF	FWI	FWM	FO	1
1	0	-102.7	58.6	239.7	239.7	0.0	1
1	1	-126.7	91.1	549.7	549.7	0.0	1
1	2	-91.7	77.3	379.7	379.7	0.0	1
1	3	-113.7	99.3	689.7	689.7	0.0	1
1	4	-86.7	112.4	999.7	999.7	0.0	1
1	5	-102.7	121.9	1309.7	1309.7	0.0	1
1	6	-81.7	129.4	1619.7	1619.7	0.0	1
1	7	-98.7	135.5	1929.7	1929.7	0.0	1
1	8	-77.7	140.7	2239.7	2239.7	0.0	1
2	0	-37.3	15.9	119.9	119.9	0.0	1
2	1	-37.3	28.9	50.1	50.1	0.0	3
2	2	-36.8	47.5	189.9	189.9	0.0	1
2	3	-38.8	73.6	344.9	344.9	0.0	1
2	4	-38.3	87.6	499.9	499.9	0.0	1
2	5	-41.8	97.4	654.9	654.9	0.0	1
2	6	-39.3	105.0	809.9	809.9	0.0	1
2	7	-41.8	111.2	964.9	964.9	0.0	1
2	8	-39.3	116.4	1119.9	1119.9	0.0	1
3	0	-33.9	0.0	80.0	80.0	325.0	0
3	1	-34.9	52.3	33.4	33.4	0.0	3
3	2	-33.2	21.0	126.6	126.6	0.0	1
3	3	-39.6	56.7	229.9	229.9	0.0	1
3	4	-30.6	72.3	333.2	333.2	0.0	1
3	5	-40.6	82.6	436.6	436.6	0.0	1
3	6	-31.6	90.4	539.9	539.9	0.0	1
3	7	-41.6	96.8	643.2	643.2	0.0	1
3	8	-31.6	102.1	746.6	746.6	0.0	1
4	0	-25.9	13.1	60.1	60.1	0.0	3
4	1	-24.9	65.1	25.1	25.1	0.0	3
4	2	-25.9	0.0	97.6	97.6	315.3	0
4	3	-25.4	42.3	172.4	172.4	0.0	1
4	4	-25.4	60.4	249.9	249.9	0.0	1
4	5	-26.2	71.6	327.4	327.4	0.0	1
4	6	-25.9	79.8	404.9	404.9	0.0	1
4	7	-26.2	86.3	482.4	482.4	0.0	1
4	8	-24.9	91.8	559.9	559.9	0.0	1
5	0	-24.1	31.9	48.1	48.1	0.0	3
5	1	-26.1	74.1	20.1	20.1	0.0	3
5	2	-24.1	0.0	82.0	82.0	325.0	0
5	3	-28.0	27.9	137.9	137.9	0.0	1
5	4	-24.1	50.1	199.9	199.9	0.0	1
5	5	-28.5	62.4	261.9	261.9	0.0	1
5	6	-24.1	71.1	323.9	323.9	0.0	1
5	7	-29.2	77.9	385.9	385.9	0.0	1
5	8	-24.5	83.6	447.9	447.9	0.0	1
6	0	-23.6	43.1	40.0	40.0	0.0	3
6	1	-23.6	0.0	94.2	94.2	325.0	0
6	2	-23.6	0.0	71.6	71.6	334.6	0
6	3	-23.6	11.6	115.0	115.0	0.0	1

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Figure 13. Spurious Response Performance Printout

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And the user is requested:

* ENTER: K1, K2, K3

If the response is sinusoidal, the corresponding defining equation:

* F = K1 + K2*(SIN(K3*T + K4))**K5

* ENTER: K1, K2, K3, K4, K5

If the response is parabolic:

* F = K1 + K2*T + K3*T**2

* ENTER: K1, K2, K3

Note the FORTRAN printout for the defining equations. The user is then requested:

* FOR SEGMENT N ENTER PHASE FUNCTION DESCRIPTOR

If the response is exponential, sinusoidal, parabolic the corresponding defining equation for the arbitrary constants is printed and the user is requested to enter the corresponding set of arbitrary constants.

c) The user is then requested to provide information concerning the integration increment and the duration of the required output time response. The integration increment should be sufficiently small so that the input function and the inpulse response approximates a straight line within each increment, thereby validating the trapezoidal approximation employed. A small segment of the desired interval may be employed as a test sample and the integration increment chosen to be deliberately coarse. The increment is then halved and the computation repeated for the test sample. The process is repeated until the output signal does not vary significantly with change of integration increment. The user is advised:

* ENTER: INTEGRATION INCREMENT, NUMBER OF STEPS

* OPTION TO PRINT EVERY NTH DATA POINT; ENTER N

The integration increment is chosen to provide sufficient accuracy in the evaluation of the integrals. N is chosen to reduce the volume of printed data.

d) The user is then offered a number of data print and plot options.

* OPTION TO PRINT DATA; ENTER YES OR NO

* OPTION TO PLOT DATA; ENTER YES OR NO

If a yes response is given to the print data option:
If the receiver block set includes a detector, the amplitude and phase modulation functions at the receiver and detector inputs and the receiver output signal waveform are tabulated as functions of time.
If the receiver block set does not include a detector, the amplitude and phase modulation functions at the receiver input and output are tabulated as functions of time.
If a yes response is given to the plot data option, the user is offered a choice of one of the above signals (other than the input modulation functions) to plot on the user's I/O device.

* OPTION 1 - PREDETECTION AMPLITUDE MODULATION FUNCTION

* OPTION 2 - PREDETECTION PHASE MODULATION FUNCTION

* OPTION 3 - PREDETECTION MODULATED R.F. SIGNAL

(NOTE: "Predetection" refers to the undetected r.f. signal, whether there is a detector block or not.)
If there is a detector block, a fourth plot option is offered:

* OPTION 4 - POST DETECTION OUTPUT SIGNAL

e) Initial conditions. Based on the choice of amplitude and phase modulation descriptors the initial value is given by:
Exponential: K1 + K2
Sinusoidal: K1 + K2*(SIN(K4))**K5
Parabolic: K1
obtained by letting T = 0 in the defining function.
The initial value of the input modulation function is

$$a(0) = \rho(0)\cos|\phi(0)| + j\,\rho(0)\sin|\phi(0)|$$

where $\rho(0)$ is the initial value of the amplitude function and $\phi(0)$ is the initial value of the phase function.

If the filter network function $H(S) = N(S)/d(S)$ has numerator and denominator polynomials with the same degree, the initial value of the output signal:

$$Z(0) = H(\infty)y(0)$$

where $H(\infty) = \lim_{S \to \infty} H(S)$

$y(0)$ = initial value of filter input signal.

It is assumed that the first filter in any receiver will have finite noise bandwidth so that $H(\infty)=0$. Hence $y(0)=0$ for subsequent filters. Since the subsequent filters will have $H(\infty)$ finite, $Z(0)$ is taken as zero for all filters.

f) The receiver input amplitude and phase functions are computed for any time increment, based on segment durations, amplitude and phase modulation function descriptors and segment amplitude and phase K values.

g) The output signals, Z(t) from any filter at any time increment $t = t_o + \delta$ is obtained from:

1) input signals $y(t_o)$ and $y(t_o + \delta)$
2) output signal $Z(t_o)$

based on a recursive evaluation of the convolution integral

$$Z(t) = \int_o^t y(\tau)h(t-\tau)d\tau$$

where $h(t) = \mathscr{L}^{-1} H(S)$

Hence, from (e) and (f), Z(t) is obtainable for the first filter for all t.

h) The output signal for any filter is taken as the input signal of the next filter (taking into account any mixer inversion that are present between the two filters). Since the initial value of the output signal of all filters known (paragraph e)), the output signal from all filters may be computed for a given time increment before proceding with the next increment.

i) From the complex modulation function Z(t) at the output of the last r.f filter, its amplitude, $\rho(t)$ and argument $\phi(t)$ are determined. (If the receiver block set includes a detector this is the predetector output; if not it is the receiver output). Figure 12 includes a sample tabulation of the amplitude and phase modulation functions prior to detection. (NOTE: Every Nth data point is printed based on choice of N in paragraph (c).)

j) If the receiver block set includes a detector, its output is dependent on detector type. For amplitude modulation envelope detectors, the detector output is $\rho(t)$. For amplitude modulation square law detectors, the detector output is $\rho^2(t)/2$. For phase modulation detectors, the detector output is $\phi(t)$. For frequency modulation detectors the output is $d\phi/dt$. The frequency modulation detector output at $t = t_o + \delta$ is computed as:

$$(d\phi/dt)_{t=t_o+\delta} = [\phi(t_o + \delta) - \phi(t_o)]/\delta$$

since δ is chosen suitably small.

k) If the receiver block set does not include a baseband filter, the detector output is taken as the receiver output waveform and is tabulated in 14A. If it includes one or more baseband filters, the filter outputs are obtained from the convolution integral:

$$b(t) = \int_o^t a(t)\ h(t-\tau)d\zeta$$

where $a(t)$ is the detector output signal and $h(t)$ is the baseband filter impulse response. The filter output signal is taken as the receiver output and every Nth data point is tabulated in Figure 14A.

l) After all filter outputs are computed for $t = t_o + \delta$, the variables $y(t)$ and $Z(t)$ are updated for all filters and the recursive process is repeated to determime $Z(t_o+2\delta)$ for all filters.

m) If the plot option (paragraph d) was answered yes, the selected output is scaled and every Nth data point is plotted in accordance with the choice of N (paragraph c).

n) After computations have been made for the number of increments entered in paragraph (c), and the results printed and/or plotted, the user is asked:

* CONTINUE SOLUTION?

If the user's response is no, the program advances to Section 3.13. If the user responds yes, he is requested:

* OPTIONS TO CHANGE INTEGRATION INCREMENT
* ENTER: NEW INTEGRATION INCREMENT
* FOR NO CHANCE ENTER: 0
* OPTION TO PRINT EVERY NTH DATA POINT; ENTER N
* ENTER NUMBER OF ADDITIONAL INTEGRATION INCREMENTS

The user thus has free play to change the integration parameters based on the rate of change of the output signals.

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```
 IS DATA CORRECT? ANSWER YES OR NO
?YES


 ++++++  WAVEFORM RESPONSE  ++++++


 NOTE: ALL TIME INTERVALS GIVEN IN MICROSECONDS


 ENTER NUMBER OF SEGMENTS (1 TO 6) FORMING INPUT SIGNAL
 MODULATION FUNCTION
?1
FOR SEGMENT  1 ENTER SEGMENT TIME DURATION (MICROSEC)
?1000
FUNCTION DESCRIPTORS ARE: EXPONENTIAL,SINUSOIDAL,PARABOLIC
 FOR SEGMENT  1 ENTER AMPLITUDE FUNCTION DESCRIPTOR
?SIN
 F=K1+K2*(SIN(K3*T+K4))**K5
 ENTER:K1,K2,K3,K4,K5
?1,1,.01570796,0,1
 FOR SEGMENT  1 ENTER PHASE FUNCTION DESCRIPTOR
?PAR
 F=K1+K2*T+K3*T**2
 ENTER:K1,K2,K3
?0,0,0
 ENTER: INTEGRATION INCREMENT,NUMBER OF STEPS
?.1,500
 OPTION TO PRINT EVERY NTH DATA POINT: ENTER: N
?50
 OPTION TO PRINT DATA ; ENTER YES OR NO
?YES
 OPTION TO PLOT DATA? ANSWER YES OR NO
?YES
 AVAILABLE PLOT OPTIONS:
 OPTION 1 = PREDETECTION MODULATION FUNCTION AMPLITUDE
 OPTION 2 = PREDETECTION MODULATION FUNCTION PHASE
 OPTION 3 = PREDETECTION MODULATED RF SIGNAL
 ENTER INTEGER 1 TO 3
?1


                          TIME HISTORY

                   INPUT                    PREDETECTION

 TIME        AMP          FAZ(RAD)      AMP          FAZ(RAD)


 .          .10000E+01  0.            0.            0.
 .500E+01   .10785E+01  0.            .11578E-01   -.43648E-02
 .100E+02   .11564E+01  0.            .44449E-01   -.36421E-02
 .150E+02   .12334E+01  0.            .95375E-01   -.40747E-02
 .200E+02   .13090E+01  0.            .16135E+00   -.47655E-02
 .250E+02   .13827E+01  0.            .23959E+00   -.55353E-02
```

Figure 14A. Print Option Waveform Response Printout

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TIME HISTORY

	INPUT		PREDETECTION	
TIME	AMP	FAZ(RAD)	AMP	FAZ(RAD)
.	.10000E+01	0.	0.	0.
.500E+01	.10785E+01	0.	.11578E-01	-.43648E-02
.100E+02	.11564E+01	0.	.44449E-01	-.36421E-02
.150E+02	.12334E+01	0.	.95375E-01	-.40747E-02
.200E+02	.13090E+01	0.	.16135E+00	-.47655E-02
.250E+02	.13827E+01	0.	.23959E+00	-.55353E-02
.300E+02	.14540E+01	0.	.32758E+00	-.63241E-02
.350E+02	.15225E+01	0.	.42302E+00	-.71060E-02
.400E+02	.15878E+01	0.	.52385E+00	-.78680E-02
.450E+02	.16494E+01	0.	.62823E+00	-.36029E-02
.500E+02	.17071E+01	0.	.73454E+00	-.93065E-02

CONTINUE SOLUTION?
?YES
OPTIONS TO CHANGE INTEGRATION INCREMENT
ENTER:NEW INTEGRATION INCREMENT(MICROSEC)
FOR NO CHANGE ENTER : 0
?.2,4750
OPTION TO PRINT EVERY NTH DATA POINT: ENTER: N
?25
ENTER NUMBER OF ADDITIONAL INTEGRATION INCREMENTS
?4750

.550E+02	.17604E+01	0.	.84133E+00	-.99762E-02
.600E+02	.18090E+01	0.	.94734E+00	-.10611E-01
.650E+02	.18526E+01	0.	.10515E+01	-.11209E-01
.700E+02	.18910E+01	0.	.11528E+01	-.11772E-01
.750E+02	.19239E+01	0.	.12506E+01	-.12299E-01
.800E+02	.19511E+01	0.	.13440E+01	-.12791E-01
.850E+02	.19724E+01	0.	.14325E+01	-.13248E-01
.900E+02	.19877E+01	0.	.15156E+01	-.13672E-01
.950E+02	.19969E+01	0.	.15929E+01	-.14064E-01
.100E+03	.20000E+01	0.	.16641E+01	-.14426E-01
.105E+03	.19969E+01	0.	.17289E+01	-.14758E-01
.110E+03	.19877E+01	0.	.17870E+01	-.15062E-01
.115E+03	.19724E+01	0.	.18384E+01	-.15340E-01
.120E+03	.19511E+01	0.	.18829E+01	-.15594E-01
.125E+03	.19239E+01	0.	.19204E+01	-.15824E-01
.130E+03	.18910E+01	0.	.19510E+01	-.16033E-01
.135E+03	.18526E+01	0.	.19745E+01	-.16223E-01
.140E+03	.18090E+01	0.	.19910E+01	-.16394E-01
.145E+03	.17604E+01	0.	.20007E+01	-.16549E-01
.150E+03	.17071E+01	0.	.20035E+01	-.16688E-01
.155E+03	.16494E+01	0.	.19997E+01	-.16814E-01
.160E+03	.15878E+01	0.	.19892E+01	-.16927E-01
.165E+03	.15225E+01	0.	.19724E+01	-.17028E-01
.170E+03	.14540E+01	0.	.19494E+01	-.17119E-01
.175E+03	.13827E+01	0.	.19204E+01	-.17201E-01
.180E+03	.13090E+01	0.	.18858E+01	-.17274E-01
.185E+03	.12334E+01	0.	.18456E+01	-.17340E-01
.190E+03	.11564E+01	0.	.18003E+01	-.17398E-01
.195E+03	.10785E+01	0.	.17502E+01	-.17450E-01
.200E+03	.10000E+01	0.	.16956E+01	-.17496E-01
.205E+03	.92154E+00	0.	.16368E+01	-.17536E-01
.210E+03	.84357E+00	0.	.15742E+01	-.17570E-01
.215E+03	.76656E+00	0.	.15083E+01	-.17598E-01
.220E+03	.69098E+00	0.	.14395E+01	-.17620E-01
.225E+03	.61732E+00	0.	.13681E+01	-.17635E-01
.230E+03	.54601E+00	0.	.12946E+01	-.17643E-01
.235E+03	.47750E+00	0.	.12195E+01	-.17642E-01
.240E+03	.41222E+00	0.	.11432E+01	-.17632E-01
.245E+03	.35055E+00	0.	.10662E+01	-.17603E-01
.250E+03	.29289E+00	0.	.98895E+00	-.17570E-01
.255E+03	.23959E+00	0.	.91191E+00	-.17513E-01
.260E+03	.19098E+00	0.	.83555E+00	-.17433E-01
.265E+03	.14736E+00	0.	.76034E+00	-.17322E-01
.270E+03	.10899E+00	0.	.68673E+00	-.17172E-01
.275E+03	.76121E-01	0.	.61517E+00	-.16971E-01

.140E+03	.18090E+01	0.	.19910E+01	-.16394E-01
.145E+03	.17604E+01	0.	.20007E+01	-.16549E-01
.150E+03	.17071E+01	0.	.20035E+01	-.16688E-01
.155E+03	.16494E+01	0.	.19997E+01	-.16814E-01
.160E+03	.15878E+01	0.	.19892E+01	-.16927E-01
.165E+03	.15225E+01	0.	.19724E+01	-.17028E-01
.170E+03	.14540E+01	0.	.19494E+01	-.17119E-01
.175E+03	.13827E+01	0.	.19204E+01	-.17201E-01
.180E+03	.13090E+01	0.	.18858E+01	-.17274E-01
.185E+03	.12334E+01	0.	.18456E+01	-.17340E-01
.190E+03	.11564E+01	0.	.18003E+01	-.17398E-01
.195E+03	.10785E+01	0.	.17502E+01	-.17450E-01
.200E+03	.10000E+01	0.	.16956E+01	-.17496E-01
.205E+03	.92154E+00	0.	.16368E+01	-.17536E-01
.210E+03	.84357E+00	0.	.15742E+01	-.17570E-01
.215E+03	.76656E+00	0.	.15083E+01	-.17598E-01
.220E+03	.69098E+00	0.	.14395E+01	-.17620E-01
.225E+03	.61732E+00	0.	.13681E+01	-.17635E-01
.230E+03	.54601E+00	0.	.12946E+01	-.17643E-01
.235E+03	.47750E+00	0.	.12195E+01	-.17642E-01
.240E+03	.41222E+00	0.	.11432E+01	-.17632E-01
.245E+03	.35055E+00	0.	.10662E+01	-.17603E-01
.250E+03	.29289E+00	0.	.98895E+00	-.17570E-01
.255E+03	.23959E+00	0.	.91191E+00	-.17513E-01
.260E+03	.19098E+00	0.	.83555E+00	-.17433E-01
.265E+03	.14736E+00	0.	.76034E+00	-.17322E-01
.270E+03	.10899E+00	0.	.68673E+00	-.17172E-01
.275E+03	.76121E-01	0.	.61517E+00	-.16971E-01
.280E+03	.48944E-01	0.	.54609E+00	-.16702E-01
.285E+03	.27630E-01	0.	.47991E+00	-.16342E-01
.290E+03	.12312E-01	0.	.41703E+00	-.15856E-01
.295E+03	.30827E-02	0.	.35784E+00	-.15197E-01
.300E+03	.47606E-12	0.	.30269E+00	-.14292E-01
.305E+03	.30826E-02	0.	.25192E+00	-.13031E-01
.310E+03	.12312E-01	0.	.20584E+00	-.11243E-01
.315E+03	.27630E-01	0.	.16473E+00	-.86596E-02
.320E+03	.48943E-01	0.	.12883E+00	-.48459E-02
.325E+03	.76120E-01	0.	.98380E-01	.88864E-03
.330E+03	.10899E+00	0.	.73552E-01	.95799E-02
.335E+03	.14736E+00	0.	.54503E-01	.22452E-01
.340E+03	.19098E+00	0.	.41352E-01	.39704E-01
.345E+03	.23959E+00	0.	.34175E-01	.57252E-01
.350E+03	.29289E+00	0.	.33002E-01	.65623E-01
.355E+03	.35055E+00	0.	.37830E-01	.59937E-01
.360E+03	.41221E+00	0.	.48636E-01	.46499E-01
.365E+03	.47750E+00	0.	.65362E-01	.32872E-01
.370E+03	.54601E+00	0.	.87910E-01	.21946E-01
.375E+03	.61732E+00	0.	.11614E+00	.13819E-01
.380E+03	.69098E+00	0.	.14988E+00	.78573E-02
.385E+03	.76655E+00	0.	.18893E+00	.34399E-02
.390E+03	.84356E+00	0.	.23303E+00	.10657E-03
.395E+03	.92154E+00	0.	.28192E+00	-.24605E-02
.400E+03	.10000E+01	0.	.33530E+00	-.44771E-02

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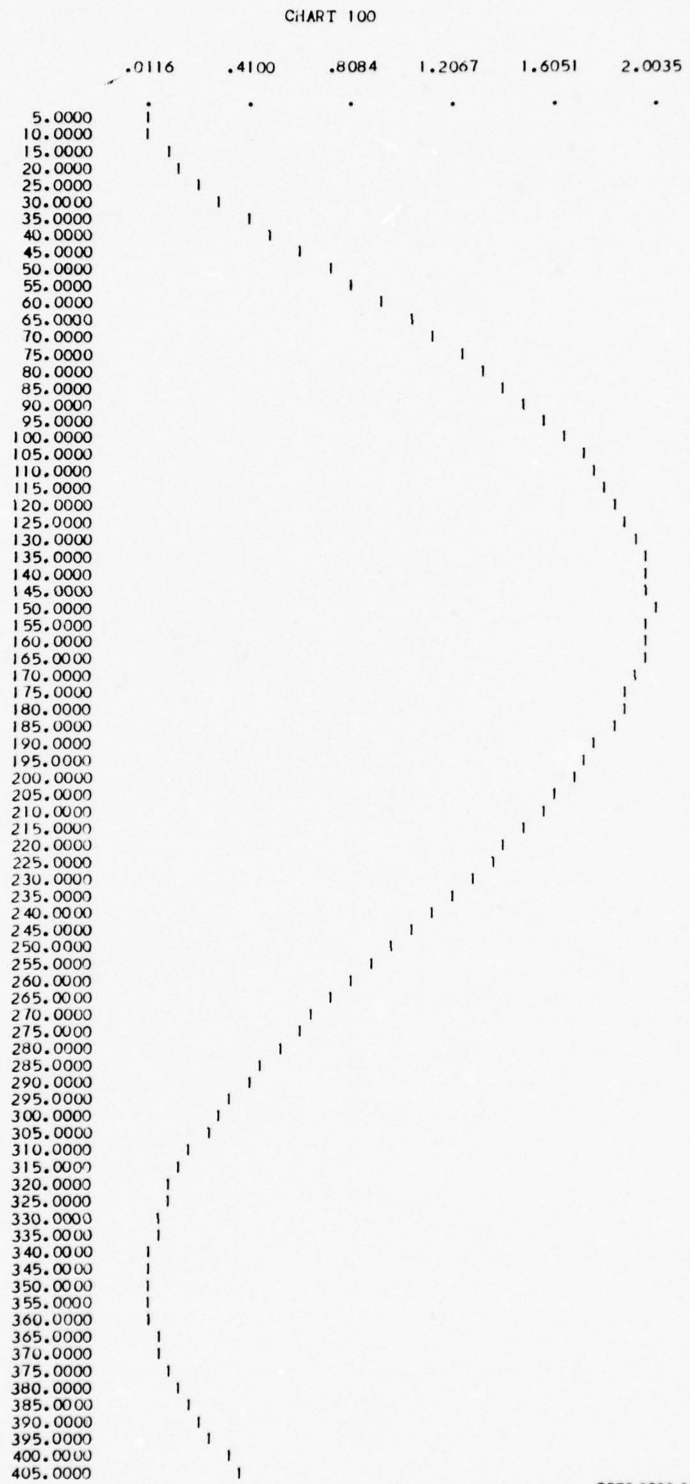

Figure 14B. Plot Option

3.13 RERUN

The user is requested:

* RERUN THE PROGRAM? ANSWER YES OR NO

If no the program terminates.

If yes the program returns to Section 3.1.1.

The yes option is useful to determine the effects on performance of changing a given data parameter or set of parameters.

SECTION IV

SYNTHESIZER COMPUTER PROGRAM, SYN

4.1 PRELIMINARY INFORMATION

The synthesizer computer program, like the signal path program, is interactive. The format for discussion in this section, of program instructions, requests for information and user responses, is similar to that employed in Section 3.

4.1.1 Previous File Status

* HAS A DATA FILE BEEN OPENED PREVIOUSLY FOR THIS SYNTHESIZER?

If no a new file is opened

If yes the data in the file is read into the computer work memory and program advances to Section 4.2.2.

4.1.2 Desired Computations

* PRINT SYNTHESIZER FREQUENCY PLAN?
* COMPUTE SPURIOUS RESPONSE PERFORMANCE?
* COMPUTE NOISE MODULATION PERFORMANCE
* COMPUTE ACQUISITION CHARACTERISTICS?

The computations corresponding to those questions for which the user provides a yes response are carried out in sequence.

4.2 DATA ENTRY AND PRINTOUT

4.2.1 Data Entry

If the response to the question in Section 4.1.1 is no the user is prompted with a sequence of requests for information relative to the synthesizer block diagram configuration and component parameters.

4.2.1.1 Basic Parameters - The user is asked to provide information, (readily obtained by inspection of the synthesizer block diagram) relative to the number of phase locked loops; number of mixers, number of synthesizer outputs (from 1 to 5) and a list of output VCO's. NOTE: Phase locked loops and their respective VCO's phase comparators and loop filters are numbered in common.

* ENTER: NUMBER OF PHASE LOCKED LOOPS
* ENTER: NUMBER OF MIXERS
* ENTER: NUMBER OF SYNTHESIZER OUTPUTS
* ENTER INTEGER: 1 TO 5
* ENTER: LIST OF OUTPUT VCO'S

The user is also asked to provide the frequency of the synthesizer standard and, if there is an independent source other than the standard to which the output signals are referenced, to provide its frequency.

*   ENTER SYNTHESIZER STANDARD FREQUENCY (MHZ)
*   ENTER FREQUENCY (MHZ) OF INDEPENDENT SOURCE NOT
*   REFERENCED TO SYNTHESIZER STANDARD FREQUENCY
*   IF NONE, ENTER 0
         The user is also requested
*   ENTER RECEIVER NOISE BANDWIDTH (MHZ)

4.2.1.2 Block Diagram Information - The user is asked to provide information relative to the matrices that represent the synthesizer block diagram. Three matrices are defined:

a) Mixer output reference matrix
b) Reference input matrix
c) Feedback input matrix

Figure 16A is a worksheet that may be used to generate the matrix element data from the block diagram. One worksheet is used for each matrix. If there are L phase locked loops and M mixers, the data is entered on L+M+2 columns of the 26 indicated on the worksheet. The mixer output matrix data will be entered on M rows of the 12 rows provided on the worksheet; the reference input and feedback input matrices will use L rows.

The first column is used for the frequency standard. The second column is used for another frequency reference (if there is one); if there is no other frequency reference this column is blank. The columns from 3 to L+2 are used for L loop VCO's. Columns from L+3 to L+M+2 are used for M mixer outputs.

For the mixer output matrix, the rows correspond to the vector of M mixer outputs. The elements of the matrix are assigned values in accordance with the following rules: The elements are equal to zero for columns representing sources that do not feed the mixer corresponding to a given row. The magnitude of non-zero elements are equal to the multiplication ratio when there is a frequency multiplier between the source corresponding to a given column and the input to the mixer corresponding to a given row. The magnitude is equal to the reciprocal of the division ratio if there is a frequency divider between the source and mixer input. The magnitude is equal to 1 if there is neither a frequency miltiplier or divider.

There will be two non-zero elements for each row of the mixer output matrix (each corresponding to a mixer input). The signs on the two elements are each positive if the mixer output frequency is the sum of the two input frequencies. If the mixer output frequency is the difference of the two input frequencies, the appropriate non-zero element is assigned a negative sign.

To systemetize the assignment of non-zero element values, they are entered as rational fractions, assigning negative values to the numerators where appropriate.

To enter a non-zero matrix element, the column number of the matrix and the numerator and denominator integer values are entered by the user. Since spur and noise phase modulation of the mixer output are dependent on which of the two inputs to the mixer is the oscillator, it is necessary to distinguish the input signals. The oscillator inputs may be encircled on the worksheet prior to data entry as is indicated in the sample (Figure 16B).

Note: Sample printouts apply to the sample block diagram given in Figure 15.

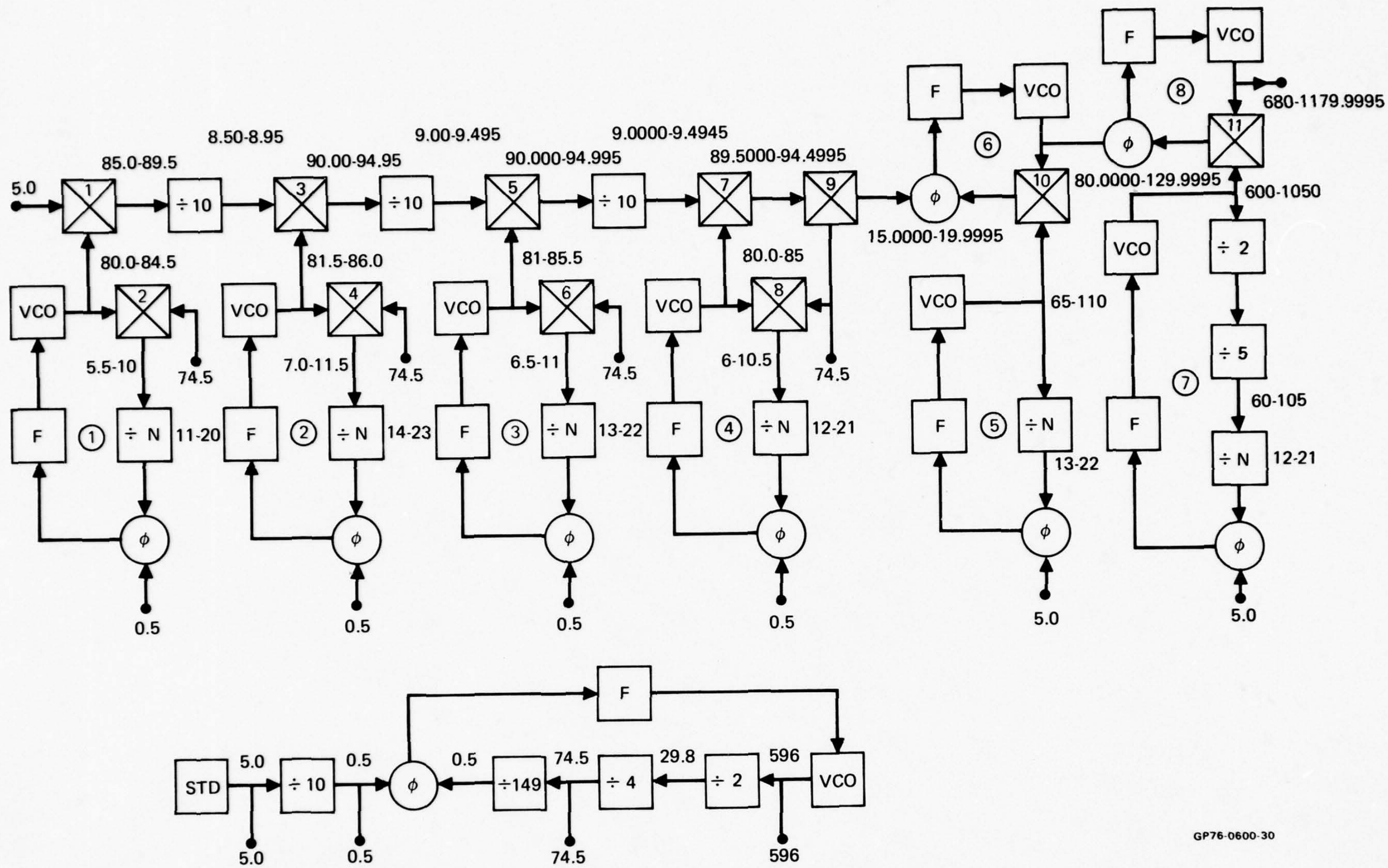

Figure 15. Sample Synthesizer Block Diagram

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Matrix Name: ______________________

Source		Std	Ref											
Sig	Row \ Col	1	2	3	4	5	6	7	8	9	10	11	12	13
	1													
	2													
	3													
	4													
	5													
	6													
	7													
	8													
	9													
	10													
	11													
	12													

Figure 16A. Block Diagram Matrix Data Sheet

12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

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Matrix Name: MIXER OUTPUT MATRIX

Source		Std	Ref	V1	V2	V3	V4	V5	V6	V7	V8	M1	M2	M3	M
Sig	Row / Col	1	2	3	4	5	6	7	8	9	10	11	12	13	1
M1	1	10/1		1/1											
M2	2	-149/1		1/1											
M3	3				1/1							1/10			
M4	4	-149/1			1/1										
M5	5					1/1								1/10	
M6	6	-149/1				1/1									
M7	7						1/1								
M8	8	-149/1					1/1								
M9	9	-149/1													
M10	10							-1/1	1/1						
M11	11									-1/1	1/1				
	12														
		U		E											

Figure 16B. Block Diagram Matrix Data Sheet

V8	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11					
10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	1/10															
			1/10													
					1/10											
							1/1									
1/1																
	W															

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The user is provided with a printout of these rules for data entry, examples, and guided by a sequence of requests for data:

* BLOCK DIAGRAM INFORMATION ENTERED AS THREE MATRICES
* LABELED: MIXER OUTPUT, REFERENCE INPUT, FEEDBACK INPUT
* EACH MATRIX HAS C COLUMNS

NOTE: C is computed from (C=L+M+2) and inserted in the above instruction.

* COLUMN 1 IS FOR FREQUENCY STANDARD
* COLUMN 2 IS FOR INDEPENDENT FREQUENCY SOURCE
* COLUMNS 3 THROUGH N1 ARE FOR N2 VCO FREQUENCIES (N1=L+2, N2=L)
* COLUMNS N3 THROUGH N4 ARE FOR N5 MIXER FREQUENCIES (N3=L+3, N4=L+M+2, N5=M)
* MATRIX ELEMENTS ARE POSITIVE OR NEGATIVE RATIONAL FRACTIONS
* ENTER EACH NON-ZERO ELEMENT AS NUMERATOR, DENOMINATOR
* FOR NEGATIVE ELEMENT NUMERATOR IS NEGATIVE
* EXAMPLE: -1, 1731 ENTRY FOR -1/1731

The user is instructed in the method for entry of matrix element data for programmable elements:

* SOME MATRIX ELEMENTS MAY TAKE ON A RANGE OF VALUES
* PROGRAMMABLE COMPONENTS: ENTER 99999, 1 FOR SUCH ELEMENTS

NOTE: Do not use a minus sign when entering the programmable component indication: 99999,1.

The user will then be asked to enter the minimum and maximum values of the programmable element in the form: numerator, denominator, numerator, denominator.

The sequence of user instructions relative to the mixer output matrix:

* ENTER MIXER OUTPUT MATRIX
* DIMENSION: N6 ROWS; N7 COLUMNS (N6=M; N7=L+M+2)
* EACH ROW HAS 2 NON-ZERO ELEMENTS
* ONE ELEMENT FOR MIXER OSC; ONE FOR MIXER SIGNAL

For each row, in turn, the user is requested:

* FOR ROW, I, ENTER OSCILLATOR ELEMENT (I=1 to M)
* COLUMN, NUMERATOR, DENOMINATOR

After the user enters the oscillator elements,

* FOR ROW, I, ENTER SIGNAL ELEMENT (I=1 to M)
* COLUMN, NUMERATOR, DENOMINATOR

If the user enters 99999,1 for any numerator, denominator to indicate a programmable element, he is requested:

* FOR ELEMENT I, J ENTER MIN AND MAX VALUES

(I is the row, J is the column of the mixer output matirx)

* NUMERATOR, DENOMINATOR, NUMERATOR, DENOMINATOR

A similar sequence of instructions are employed for the reference input matrix:

* ENTER REFERENCE INPUT MATRIX
* DIMENSIONS: N8 ROWS; N9 COLUMNS (N8=L; N9=L+M+2)
* EACH ROW HAS 1 NON-ZERO ELEMENT

For each row, in turn, the user is requested:

* ENTER ROW I (I=1 to L)
* COLUMN, NUMERATOR, DENOMINATOR

If the user enters 99999,1 for the numerator and denominator he is requested:

* FOR ELEMENT I, J ENTER MIN AND MAX VALUES
* NUMERATOR, DENOMINATOR, NUMERATOR, DENOMINATOR

The feedback input matrix data is entered in response to a similar sequence of instructions. (NOTE: No non-zero elements occur in the first two columns.)

A running count is kept of the programmable elements, identified in their sequence of entry.

4.2.1.3 Component Parameters - The library of synthesizer modules modeled consists of mixers, phase comparators, VCO's and filters. Table 2 lists these module types and the required data associated with each module type. The numbers in the brackets indicate the sections of this manual that may be referenced for discussion of the module parameters.

a) Mixers

As in the signal path program, the mixer catalog and data file, generated by an auxiliary program is called and its contents are read into the synthesizer program work memory. Instructions for data entry and update of the auxiliary mixer catalog program are given in Section 5. With the mixer parameters stored in the work memory, the user is required to supply only the mixer catalog number and signal level for each mixer.

The user has the option to obtain a listing of the mixers in the mixer catalog and to obtain a printout of the spur product table (either as intercepts or as spur relative to the signal level for any given signal input level).

Table 2. Data Requirements for Synthesizer Components

Component	Required Data
Mixer	1. Mixer Catalog Number 2. Signal Level (dBm)
Phase Comparators	1. Type (Sinusoidal, Multilinear) 2. Gain Constant (Volt/rad) 3. Reference Leakage, Bias (dB rad) 4. Output Resistance (ohm)
VCO	1. Gain Constant (MHz/Volt) 2. VCO Phase Noise Modulation Spectrum (dB rad/Hz) 2a. Specified Frequency, Phase Noise Level
Filter	1. Gain Constant 2. Number of Poles and Zeros 3. Pole and Zero Location 4. Noise Figure (dB)
Divider	1. Divider Ratio
Multiplier	1. Multiplier Ratio

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* LIST MIXER CATALOG FILE? (ANSWER YES OR NO)

If yes the catalog of mixers is printed. Note the sample, Figure 5.

If both of the questions of Section 4.1.2 relative to spurious or noise performance are anwered no the program advances to Paragraph b).

If either of the questions of Section 4.1.2 is answered yes the user is advised:

* MIXER SPUR PRODUCT INTERCEPT DATA IS TABULATED IN TWO WAYS:
* SPURPRODUCT INTERCEPTS (TABLE 0) OR
* SPUR PRODUCT CONVERSION LOSS FOR GIVEN SIGNAL LEVEL (TABLE 1)

The user is requested:

* PRINT MIXER SPUR TABLE? (Answer yes or no)

If yes the user is requested:

* ENTER ONE MIXER NUMBER FROM CATALOG AND
* SPUR DATA TABLE DESIRED
* EXAMPLE 6, 0

After the user enters the requested data, the mixer catalog number and the descriptor from the catalog consisting of manufacturer's name, manufacturer's part number and oscillator power level are printed together with the mixer conversion loss.

The requested spur table is printed for values of j, k where $0 \leq j \leq 7$; $0 \leq k \leq 8$. For unknown values, 99 is printed.

If the requested spur table is 0 the value printed for each j, k is $P_{j,k}$ (refer to Section 3.11.b.4).

If the requested spur Table is 1 the user is requested to enter the mixer signal leve, P_a:

* SPECIFY MIXER SIGNAL INPUT LEVEL (dbm)

The value printed for each j, k is $R_{j,k}$ corresponding to the input level P_a (refer to Section 3.11.b.4).

The user is then asked:

* PRINT ANOTHER MIXER SPUR TABLE?

If yes the user is requested:

* ENTER ONE MIXER NUMBER FROM CATALOG AND
* SPUR TABLE DESIRED

and the spur data printout sequence is repeated for the new spur table. If the response to * PRINT MIXER SPUR TABLE? or * PRINT ANOTHER MIXER SPUR TABLE? is no (indicating that the user needs no further catalog information to specify the synthesizer mixers) he is requested for each mixer, I, in turn ($1 \leq I \leq M$)

* FOR MIXER I ENTER NUMBER FROM MIXER CATALOG
* AND MIXER INPUT SIGNAL LEVEL (dbm)

b) Phase Comparators

The sequence of questions relative to phase comparator data entry follow: (Requests for data are omitted in accordance with the following code based upon responses to questions in Section 4.1.2 relative to performance computations.)

(S) Omitted if response to question relative to spurious response performance is <u>no</u>.

(N) Omitted if response to question relative to noise response performance is <u>no</u>.

(A) Omitted if response to question relative to acquisition characteristic is <u>no</u>.

The user is requested, for each phase comparator, I, in turn ($1 \leq I \leq L$)

```
*       (A)  ENTER PHASE COMPARATOR TYPE:
*       (A)  1 FOR SINUSOIDAL; 2 FOR MULTILINEAR
```

Thereupon, he is requested:

```
*       FOR PHASE COMPARATOR I, ENTER GAIN CONSTANT KD
*       VOLTS PER RADIAN
*       FOR MULTILINEAR PHASE COMPARATOR KD IS SLOPE OF OUTPUT
*       FOR SINUSOIDAL PHASE COMPARATOR KD IS PEAK SLOPE
*       CORRESPONDING TO ZERO OUTPUT
```

After the user enters K_D he is requested to enter the reference frequency leakage (ϕ_D), bias (ϕ_B) and phase comparator output source resistance. ϕ_D and ϕ_B are entered as decibels below K_D

```
*       (S)  ENTER REFERENCE FREQUENCY LEAKAGE (DB BELOW KD)
*       (A)  ENTER PHASE COMPARATOR BIAS (DB BELOW KD)
*       (N)  ENTER PHASE COMPARATOR OUTPUT SOURCE RESISTANCE (OHMS)
```

c) VCO'S

The user is advised:

```
*       VCO GAIN CONSTANT (MHZ/VOLT)
```

The user is requested for each VCO, I, in turn ($1 \leq I \leq L$)

```
*       FOR VCO, LOOP I, ENTER VCO GAIN CONSTANT
*       AT MAXIMUM, MINIMUM VCO FREQUENCIES
```

If the question of Section 4.1.2 relative to noise modulation performance is <u>no</u> the program advances to Paragraph d).

If <u>yes</u> the user is requested:

```
*   VCO NOISE PHASE MODULATION SPECTRUM
*   ENTER PHASE MOD. (DB BELOW 1 RADIAN/HZ) AT 2 TO 8 FREQUENCIES
*   SPECTRUM INTERPOLATED BETWEEN SELECTED FREQUENCIES
*   FOR VCO, LOOP I, ENTER NUMBER OF FREQUENCIES DEFINING
*   VCO PHASE NOISE MODULATION SPECTRUM
```

If the user enters an integer N ($2 \leq N \leq 8$), for each integer from 1 to N, the user is requested:

* ENTER: OFFSET FREQUENCY, PHASE DEVIATION (DB BELOW 1 RAD/HZ)

It is noted that the VCO phase noise spectrum is entered as a piece-wise continuous curve with linear segments when plotted as decibels vs log f (where f is the frequency offset from the VCO carrier.

d) Loop Filters

Phase locked loop filters are low pass devices with network functions determined by a gain constant and the location of the poles and zeros. The user is advised:

* LOOP FILTER TRANSFER FUNCTION
* (FILTER BETWEEN PHASE COMPARATOR AND VCO)

* TRANSFER FUNCTION CHARACTERIZED BY FILTER GAIN CONSTANT
* AND LOCATION IS COMPLEX S PLANE OF ZEROS AND POLES

* NO POLE CAN HAVE POSITIVE REAL PART
* NUMBER OF ZEROS LESS THAN OR EQUAL TO NUMBER OF POLES

* POLES MAY BE SIMPLE OR DOUBLE
* FOR POLES WITH MULTIPLICITY GREATER THAN 2
* ENTER EXCESS POLES WITH SMALL PERTURBATION OF IMAGINARY PART

* UNIT FOR POLES AND ZEROS: (RAD/SEC) * 1E6 = 2*PI*MHZ

* NOTE: IF FILTER TRANSFER FUNCTION IS NOT KNOWN
* USE UNITY GAIN TRANSFER FUNCTION

For each loop filter, I, ($1 \leq I \leq L$), the user is asked:

* USE UNITY GAIN TRANSFER FUNCTION FOR FILTER I?

If <u>yes</u> the gain constant is set equal to 1, the number of poles and zeros are set equal to zero and the next filter is considered in turn. If <u>no</u> the user is asked for the filter parameters.

* FOR FILTER I ENTER: NUMBER OF ZEROS, NUMBER OF POLES
* ENTER: FILTER GAIN CONSTANT

For each zero, J, in turn ($1 \leq J \leq NZ$); NZ = number of zeros

* ENTER: REAL PART, IMAGINARY PART FOR ZEROS

For each pole, J, in turn ($1 \leq J \leq NP$); NP = number of poles

* ENTER: REAL PART, IMAGINARY PART FOR POLES

If the question in Section 4.1.2 relative to noise performance computation is <u>no</u>, the next filter, in turn, is considered. If <u>yes</u> the user is requested:

* FOR ACTIVE FILTER ENTER NOISE FIGURE (db)
* FOR PASSIVE FILTER ENTER 0

Thereupon, the next filter, in turn, is considered. After data has been entered for all L filters the program proceeds to Section 4.2.2.

4.2.2 Data Printout

In accordance with the question asked in Section 4.1.1, data is entered for computation, either by reading a previously generated data file or by responses to the interactive questionaire described in Section 4.2.1. In either case the data is available for printout.

* BYPASS DATA PRINTOUT?

An option is available to eliminate the data printout. If the response is yes the program advances to Section 4.3. If no the synthesizer block diagram matrix and component parameter data are printed in accordance with the sample given in Figure 17.

4.3 DATA CORRECTION

The data correction processes provide for correction of all synthesizer data. These include

a) Provision for correction of all block diagram data including synthesizer basic parameters, block diagram matrices, and programmable element data.
b) Provision for correction of all synthesizer module parameter data.

After completion of the data printout the user is asked:

* IS DATA CORRECT?

If yes the data is entered into a file for future use
If no the data correction process is executed

4.3.1 Block Diagram Data Correction

4.3.1.1 Basic Parameter Data Correction - The user is asked:

* CHANGE SYNTHESIZER BASIC PARAMETERS?

If no the program advances to Section 4.3.1.2.

If yes the sequence of questions of Section 4.2.1.1 are asked, whereupon, the corrected data printout, related to basic parameters, is tabulated as shown in Figure 4-3, and the program advances to Section 4.3.1.2.

4.3.1.2 Matrix and Programmable Element Data Correction - The user may require two types of changes:

a) Changes of the ratios that determine the matrix element values (including programmable element ratios) without changing the block diagram configuration (the locations of the non-zero elements of the matrices).
b) Revisions of the block diagram configuration
The user is afforded three options: Option 1 permits complete re-entry of all matrix data to effect revisions of the block diagram configuration. Option 2 permits change of the values of the programmable elements without changing their location in the matrices. Option 3 permits change of individual rows of selected matrices. The user is advised:

* OPTIONS ARE AVAILABLE TO:
* (1) REENTER MATRIX DATA INCLUDING PROGRAMMABLE ELEMENTS
* (2) CORRECT VALUES OF THE PROGRAMMABLE ELEMENTS
* (3) CORRECT INDIVIDUAL ROWS OF THE MATRICES

* * * * * * * * * * * * * * * * * *

DATA
****

BASIC PARAMETERS
***** **********

LOOPS	MIXERS	OUTPUTS	STD(MHZ)	IND(MHZ)	BW(MHZ)
8	11	1	.500	0.000	.010

OUTPUTS: 8

MATRIX DATA
****** ****

MIXER OUTPUT MATRIX NON-ZERO ELEMENTS

	OSCILLATOR ELEMENT			SIGNAL ELEMENT		
ROW	COL	NUM	DEN	COL	NUM	DEN
1	3	1	1	1	10	1
2	1	-149	1	3	1	1
3	4	1	1	11	1	10
4	1	-149	1	4	1	1
5	5	1	1	13	1	10
6	1	-149	1	5	1	1
7	6	1	1	15	1	10
8	1	-149	1	6	1	1
9	1	-149	1	17	1	1
10	8	1	1	7	-1	1
11	9	-1	1	10	1	1

REFERENCE INPUT MATRIX NON-ZERO ELEMENTS

ROW	COL	NUM	DEN
1	1	1	1
2	1	1	1
3	1	1	1
4	1	1	1
5	1	10	1
6	19	1	1
7	1	10	1
8	8	1	1

FEEDBACK INPUT MATRIX NON-ZERO ELEMENTS

ROW	COL	NUM	DEN
1	12	99999	1
2	14	99999	1
3	16	99999	1
4	18	99999	1
5	7	99999	1
6	20	1	1
7	9	99999	1
8	21	1	1

MATRIX PROGRAMMABLE ELEMENTS

				MINIMUM		MAXIMUM	
NO.	MATRIX	ELEMENT		NUM	DEN	NUM	DEN
1	3	1	12	1	20	1	11
2	3	2	14	1	23	1	14
3	3	3	16	1	22	1	13
4	3	4	18	1	21	1	12
5	3	5	7	1	22	1	13
6	3	7	9	1	210	1	120

Figure 17. Sample Data Printout for Synthesizer of Figure 15

```
VCO PARAMETERS
*** **********

VCO GAIN CONSTANT(MHZ/VOLT)
*** **** ******** *** ****

LOOP      KVMIN          KVMAX
1        .144E+01       .144E+01
2        .161E+01       .137E+01
3        .164E+01       .139E+01
4        .167E+01       .142E+01
5        .650E+00       .650E+00
6        .800E+00       .800E+00
7        .700E+01       .700E+01
8        .500E+01       .500E+01

KVMIN,KVMAX=VCO GAIN CONSTANT AT MIN,MAX VCO FREQUENCIES

VCO NOISE SPECTRA
*** ***** *******
 VCO NOISE SPECTRUM,LOOP    1
FREQ      .001      .010      .100     1.000    10.000
-DB       48.0      78.0     108.0     120.0     120.0
 VCO NOISE SPECTRUM,LOOP    2
FREQ      .001      .010      .100     1.000    10.000
-DB       48.0      78.0     108.0     120.0     120.0
 VCO NOISE SPECTRUM,LOOP    3
FREQ      .001      .010      .100     1.000    10.000
-DB       48.0      78.0     108.0     120.0     120.0
 VCO NOISE SPECTRUM,LOOP    4
FREQ      .001      .010      .100     1.000    10.000
-DB       48.0      78.0     108.0     120.0     120.0
 VCO NOISE SPECTRUM,LOOP    5
FREQ      .001      .010      .100     1.000    10.000
-DB       48.0      78.0     108.0     120.0     120.0
 VCO NOISE SPECTRUM,LOOP    6
FREQ      .001      .010      .100     1.000    10.000
-DB       48.0      78.0     108.0     120.0     120.0
 VCO NOISE SPECTRUM,LOOP    7
FREQ      .001      .010      .100     1.000    10.000
-DB       20.0      50.0      80.0     110.0     120.0
 VCO NOISE SPECTRUM,LOOP    8
FREQ      .001      .010      .100     1.000    10.000
-DB       20.0      50.0      80.0     110.0     120.0
```

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Figure 17. Sample Data Printout for Synthesizer of Figure 15 (Continued)

```
LOOP FILTER PARAMETERS
**** ****** **********

FILTER NO.  1 FILTER GAIN CONSTANT:  .29428E+02
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.35996E-04    0.                   .11383E-01    0.
FILTER NO.  2 FILTER GAIN CONSTANT:  .39147E+02
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.35591E-04    0.                  -.11255E-01    0.
FILTER NO.  3 FILTER GAIN CONSTANT:  .34259E+02
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.34168E-04    0.                  -.10805E-01    0.
FILTER NO.  4 FILTER GAIN CONSTANT:  .16820E+02
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.18517E-04    0.                  -.58556E-02    0.
FILTER NO.  5 FILTER GAIN CONSTANT:  .44282E+02
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.34168E-03    0.                  -.10805E+00    0.
FILTER NO.  6 FILTER GAIN CONSTANT:  .16629E+00
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.18678E-04    0.                  -.59065E-02    0.
FILTER NO.  7 FILTER GAIN CONSTANT:  .83807E+00
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.15440E-04    0.                  -.48829E-02    0.
FILTER NO.  8 FILTER GAIN CONSTANT:  .11805E-01
              POLES(MHZ*2*PI)              ZEROS(MHZ*2*PI)
NO.      REAL             IMAG              REAL           IMAG
 1  -.18678E-04    0.                  -.59065E-02    0.

FILTER NOISE FIGURES (DB)
 FILTER        FIG
  1          10.0
  2          10.0
  3          10.0
  4          10.0
  5          10.0
  6          10.0
  7          10.0
  8          10.0
```

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Figure 17. Sample Data Printout for Synthesizer of Figure 15 (Continued)

MIXERS
******

MIXER	CAT.NO.	LEVEL(DBM)
1	3	-13.0
2	3	-13.0
3	3	-13.0
4	3	-13.0
5	3	-13.0
6	3	-13.0
7	3	-13.0
8	3	-13.0
9	3	-13.0
10	3	-13.0
11	3	-13.0

PHASE LOCKED LOOP COMPONENT PARAMETERS
***** ****** **** ********* **********

PHASE COMPARATOR PARAMETERS
***** ********** **********

LOOP	TYPE	GAIN	LEAKAGE	BIAS	OUT RES
1	2	.100	36.0	36.0	10.0
2	2	.100	36.0	36.0	10.0
3	2	.100	36.0	36.0	10.0
4	2	.100	36.0	36.0	10.0
5	1	.400	27.0	40.0	10.0
6	1	.400	27.0	40.0	10.0
7	1	.400	27.0	40.0	10.0
8	1	.400	27.0	40.0	10.0

Figure 17. Sample Data Printout for Synthesizer of Figure 15 (Continued)

* USE OPTION 1 TO CHANGE BLOCK DIAGRAM
* USE OPTIONS 2 AND 3 FOR CHANGE OF ELEMENT VALUES

The user is asked:

* REENTER ALL MATRIX DATA? (option 1)
* ANSWER YES OR NO

If yes the program returns to Section 4.2.1.2.

If no the user is asked:

* CORRECT PROGRAMMABLE ELEMENTS? (option 2)

If no the program advances to offer the user option 3.

If yes the user is asked:

* HOW MANY PROGRAMMABLE ELEMENTS TO BE CORRECTED?

Then the user is requested:

* ENTER LIST OF PROGRAMMABLE ELEMENTS TO BE CORRECTED

The user enters a list of integers corresponding to the programmable element requiring change. The integers are separated by commas (Example: 2, 4, 5)

The program advances to offer the user option 3:

* CORRECT MIXER OUTPUT MATRIX? (option 3)

If yes the user is asked:

* HOW MANY ROWS TO BE CORRECTED?
* ENTER LIST OF ROWS TO BE CORRECTED

The program returns to the sequence of requests used to enter the mixer output matrix data whereupon, the corrected data is printed and the program advances to ask the user:

* CORRECT REFERENCE INPUT MATRIX?

If yes the same questions are asked.

* HOW MANY ROWS TO BE CORRECTED?
* ENTER LIST OF ROWS TO BE CORRECTED

The program returns to the sequence of requests used to enter the reference input matrix whereupon, the corrected data is printed and the program advances to ask the user:

* CORRECT FEEDBACK INPUT MATRIX?

followed by the same questions if the response is yes, and a return to the sequence of requests used to enter the feedback input signal whereupon, the corrected data is printed and the program advances to Section 4.3.2.

If any of the answers is no the program advances as indicated above.

4.3.2 Component Parameter Data Correction

The user is asked in turn:

* CHANGE MIXER DATA?
* CORRECT PHASE COMPARATOR PARAMETERS?
* CORRECT VCO PARAMETERS?
* CORRECT FILTER PARAMETERS?

For those questions to which a yes response is made, the user is requested:

* HOW MANY { MIXERS / PHASE COMPARATORS / VCO's / FILTERS } TO BE CORRECTED?

* ENTER LIST OF { MIXERS / PHASE COMPARATORS / VCO's / FILTERS } TO BE CORRECTED

The appropriate sequences of questions are asked relative to the parameters to be changed and the corrected data is printed.

The user is again asked:

* IS DATA CORRECT?

If no the data correction process is repeated.

If yes the data, as corrected, is stored in a memory file for future use. The program advances to Section 4.4.

4.4 DATA STORAGE

As in the signal path program, if a file had been previously opened, the user has the option at the completion of the program to retain the original synthesizer data file and/or the corrected data file. The impact of the data corrections on each performance computation can thus be ascertained.

4.5 FREQUENCY PLAN COMPUTATIONS

Synthesizer frequency plan computations are made each time the program is run regardless of user response to the questions in Section 4.1.2. These computations accomplish the following:

a) Sort the programmable element values into two lists:
One list yielding a set of VCO frequencies, each of which is at an extreme (minimum or maximum) frequency value; the other list yielding a second set of VCO frequencies, each of which is at the other extreme.
NOTES: (1) For some VCO's to be at their maximum frequencies, others may be required to be at their minimum frequencies. Thus, each set may include some VCO's at maximum and others at minimum frequency The alternate set, of course, reverses the maxima and minima.
(2) Likewise, some programmable elements may obtain their maximum values for one set of VCO frequencies while other programmable elements may be required to be at their minimum values for the same set of VCO frequencies. Reversing the maximum and minimum values of the programmable elements results in the alternate set of VCO frequencies.
Notes (1) and (2) imply a 1 to 1 correspondance between VCO frequency sets and programmable element value sets. Determination of the sets of VCO frequencies and programmable element value sets will establish the extremes of noise and acquisition performance and will permit determination of worst case conditions for spurious modulation performance computations.
b) Determine the effect on each VCO frequency of a one count change in each programmable element value.
c) Determine the phase reference signal frequencies for each loop corresponding to the two lists of programmable elements.
d) Determine the signal at both inputs and the output at each mixer corresponding to the two lists of programmable elements
e) Provide a check on the data entry. If the frequency computed for each component (a through d) is not in accordance with expectations an error in data entry is indicated.

4.5.1 Sort of Programmable Elements

The following sequence of computations are accomplished:

1. The matrices are partitioned into submatrices containing:
   a) The columns corresponding to the standards (columns 1 and 2)
   b) The columns corresponding to the L VCO's (columns 3 to L+2)
   c) The columns corresponding to the M Mixers (Columns L+3 to L+M+2)
   The mixer output matrix is partitioned into submatrices U, E and W.
   The reference input matrix is partitioned into submatrices T, C and D.
   The feedback input matrix has no non-zero elements in columns 1 and 2 and is partitioned into submatrices A and B.
2. The minimum value of each programmable element is used in its appropriate position in the correct matrix A, B, C, D, E, T, U, W and matrices AA, BB, CC are computed from:

   $$AA = (C-A) + (D-B)\ (I-W)^{-1}\ E$$

   $$BB = T + (D-B)(I-W)^{-1}\ U$$

   $$CC = (D-B)(I-W)^{-1}$$
3. The set of VCO frequencies are computed from:

   $$[\dot{\theta}_V]_{SS} = -AA^{-1}\ BB\ [\omega_S]$$

   where ω_S is the vector of standard frequencies.
4. Each programmable element, in turn, is changed from its minimum to its maximum value and the changes in all VCO frequencies are noted for each programmable element change. Also, the changes in the output VCO frequencies are noted for each programmable element change.
5. A multilevel correlation process is used to sort the programmable element values into two lists. First, all programmable elements that move an output frequency in the same direction as the first programmable element when changed from minimum to maximum value are noted and their minimum values are placed in the same list as the first programmable element minimum value. Those programmable elements that move an output frequency in the reverse direction from the change caused by the first element are noted and their maximum values are placed in the same list as the first element minimum value.
   The remaining elements undergo a second sort, with each output frequency compared with the outputs affected by elements already listed. Each time a match (or reverse match) is made, the element's minimum (or maximum) value is placed in the same list as the first element minimum value. The process converges and the complete list is obtained at the end of the second sort. The second list is derived from the first list as its complement wherein, each maximum value in the first list is replaced by a minimum value in the alternate list (and vice versa). Parallel computations are made with all programmable elements set to the values corresponding to the two lists which are printed in accordance with the sample printout of Figure 18. (NOTE: The two lists are referred to as column 1 and column 2 in the printouts).

```
 IS DATA CORRECT?
?YES

*   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *

 SYNTHESIZER FREQUENCY PLAN
 *********** ********* ****

 ALL FREQUENCIES GIVEN IN MHZ

 VCO FREQUENCY CHANGE FOR UNIT CHANGE IN PROGRAMMABLE ELEMENTS
 *** ********* ****** *** **** ****** ** ************ ********
 VCO\PROG. ELEM. NO.: 1               2               3               4
  1            .500000E+00    0.              0.              0.
  2           0.             .500000E+00     0.              0.
  3           0.             0.              .500000E+00     0.
  4           0.             0.              0.              .500000E+00
  5           0.             0.              0.              .505275E-13
  6            .500000E-03   .500000E-02     .500000E-01     .500000E+00
  7           0.             0.              0.              0.
  8            .500000E-03   .500000E-02     .500000E-01     .500000E+00

 VCO\PROG. ELEM. NO.: 5               6
  1           0.             0.
  2           0.             0.
  3           0.             0.
  4           0.             0.
  5            .500000E+01   0.
  6            .500000E+01   0.
  7           0.             .500000E+01
  8            .500000E+01   .500000E+01

 SORT OF PROGRAMMABLE ELEMENTS
 **** ** ************ ********
                                     COLUMN 1        COLUMN 2
NO.      MATRIX      ELEMENT         NUM    DEN      NUM    DEN
 1         3          1   12          1      20       1      11
 2         3          2   14          1      23       1      14
 3         3          3   16          1      22       1      13
 4         3          4   18          1      21       1      12
 5         3          5    7          1      22       1      13
 6         3          7    9          1     210       1     120

 VCO AND REFERENCE FREQUENCIES
 *** *** ********* ***********

                     COLUMN 1                           COLUMN 2
 LOOP            VCO            REF                 VCO             REF
  1          .84500E+02     .50000E+00          .80000E+02      .50000E+00
  2          .86000E+02     .50000E+00          .81500E+02      .50000E+00
  3          .85500E+02     .50000E+00          .81000E+02      .50000E+00
  4          .85000E+02     .50000E+00          .80500E+02      .50000E+00
  5          .11000E+03     .50000E+01          .65000E+02      .50000E+01
  6          .13000E+03     .20000E+02          .80000E+02      .15000E+02
  7          .10500E+04     .50000E+01          .60000E+03      .50000E+01
  8          .11800E+04     .13000E+03          .68000E+03      .80000E+02
```

Figure 18. Synthesizer Frequency Plan Printout

MIXERS
******

FREQUENCIES, MIXER NUMBER 1
************ ***** ****** **

MIX	COL	OSC	SIG	OUT
1	1	.845000E+02	.500000E+01	.895000E+02
1	2	.800000E+02	.500000E+01	.850000E+02

FREQUENCIES, MIXER NUMBER 2
************ ***** ****** **

MIX	COL	OSC	SIG	OUT
2	1	.745000E+02	.845000E+02	.100000E+02
2	2	.745000E+02	.800000E+02	.550000E+01

FREQUENCIES, MIXER NUMBER 3
************ ***** ****** **

MIX	COL	OSC	SIG	OUT
3	1	.860000E+02	.895000E+01	.949500E+02
3	2	.815000E+02	.850000E+01	.900000E+02

FREQUENCIES, MIXER NUMBER 4
************ ***** ****** **

MIX	COL	OSC	SIG	OUT
4	1	.745000E+02	.860000E+02	.115000E+02
4	2	.745000E+02	.815000E+02	.700000E+01

FREQUENCIES, MIXER NUMBER 5
************ ***** ****** **

MIX	COL	OSC	SIG	OUT
5	1	.855000E+02	.949500E+01	.949950E+02
5	2	.810000E+02	.900000E+01	.900000E+02

FREQUENCIES, MIXER NUMBER 6
************ ***** ****** **

MIX	COL	OSC	SIG	OUT
6	1	.745000E+02	.855000E+02	.110000E+02
6	2	.745000E+02	.810000E+02	.650000E+01

FREQUENCIES, MIXER NUMBER 7
************ ***** ****** **

MIX	COL	OSC	SIG	OUT
7	1	.850000E+02	.949950E+01	.944995E+02
7	2	.805000E+02	.900000E+01	.895000E+02

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Figure 18. Synthesizer Frequency Plan Printout (Continued)

```
FREQUENCIES, MIXER NUMBER  8
************ ***** ****** **

MIX  COL       OSC            SIG            OUT
 8    1    .745000E+02    .850000E+02    .105000E+02
 8    2    .745000E+02    .805000E+02    .600000E+01

FREQUENCIES, MIXER NUMBER  9
************ ***** ****** **

MIX  COL       OSC            SIG            OUT
 9    1    .745000E+02    .944995E+02    .199995E+02
 9    2    .745000E+02    .895000E+02    .150000E+02

FREQUENCIES, MIXER NUMBER 10
************ ***** ****** **

MIX  COL       OSC            SIG            OUT
10    1    .130000E+03    .110000E+03    .199995E+02
10    2    .800000E+02    .650000E+02    .150000E+02

FREQUENCIES, MIXER NUMBER 11
************ ***** ****** **

MIX  COL       OSC            SIG            OUT
11    1    .105000E+04    .118000E+04    .130000E+03
11    2    .600000E+03    .680000E+03    .800000E+02
```

GP76-0600-50

Figure 18. Synthesizer Frequency Plan Printout (Continued)

4.5.2 VCO Frequency Change for Unit Change of Programmable Elements

The VCO frequency change for each programmable element change was obtained in Section 4.5.1 (4). Dividing by the difference in programmable element values provides the required sensitivity of VCO frequency to programmable element variation. A sample printout of the computed sensitivity is given in Figure 18 (together with the sample printout of the programmable element sort).

4.5.3 VCO and Reference Frequencies

The entire first list (column 1) of sorted programmable elements is entered into the appropriate matrix locations and matrices AA, BB, CC and the steady state VCO frequencies computed as in Sections 4.5.1(2) and 4.5.1(3).

The steady state mixer output frequency vector is computed from:

$$[\dot{\theta}_M]_{ss} = (I-W)^{-1} \ (U-E \ AA^{-1} \ BB) \ [\omega_S]$$

The vector of steady state reference frequencies is computed from:

$$[\dot{\theta}_R]_{ss} = A[\dot{\theta}_V]_{ss} + B \ [\dot{\theta}_M]_{ss}$$

The computation is repeated for the alternate list (column 2) of sorted programmable elements.

A printout of VCO and Reference steady state frequencies is obtained if the answer to the question in Section 4.1.2 relative to frequency plant computations is yes. A sample printout is given in Figure 18.

4.5.4 Steady State Mixer Frequencies

The steady state mixer output frequencies were computed in Section 4.5.3 for both lists of programmable element values. The mixer input frequencies are determined from:

$$[\dot{\theta}_M]_{ss} = [U:E:W] \ [\omega_S:\dot{\theta}_V:\dot{\theta}_M]^T_{ss}$$

where T indicates the transpose of the adjoined vector. For each row the two non-zero terms are evaluated to give the steady state oscillator and signal input frequencies to each mixer. These computations are made for both lists of programmable element values.

A printout of mixer steady state input and output signal frequencies is obtained if the response to the question in Section 4.1.2 relative to frequency plan computation is yes. A sample printout is given in Figure 18.

4.6 SPURIOUS PHASE MODULATION

If the response to the question in Section 4.1.2 relative to spurious response performance is no the program advances to Section 4.7.

If yes spurious phase modulation due to phase comparator and mixer spurs is computed.

4.6.1 Phase Comparator Reference Leakage Spurs

The steady state reference frequency for each loop phase comparator has been computed in Section 4.5.3 for both lists of programmable elements. The filtering at VCO i for the spurious component at reference frequency ω_{Rj} in loop j, is obtained as $|\rho_{i,j}(S)|_{S=j\omega_{Rj}}$, where

$$\rho(S) = (KF(S)/S)R(S) = (KF(S)/S)(I-AAKF(S)/S)^{-1}$$

The diagonal matrix KF(S)/S is computed for $S=j\omega_{Rj}$: AA has been computed in Section 4.5.1(2) so that $R(j\omega_{Rj})$ and $\rho(j\omega_{Rj})$ are obtained by matrix algebraic manipulation.

The filtering between each phase comparator and each output VCO is printed together with the reference frequency leakage generated by each phase comparator. A sample printout is given in Figure 19.

4.6.2 Mixer Spurs

A spur, generated at mixer ℓ, at a frequency offset from $\omega_{M\ell}$ by $\omega_{\delta\ell}$ provides phase modulation of the mixer output signal:

$$\phi_{M\delta\ell} = K_{\delta\ell} \sin (\omega_{\delta\ell} + \psi_{\delta\ell})$$

Where $K_{\delta\ell}$ is the ratio of the amplitude of the spur at frequency offset $\omega_{\delta\ell}$ to the mixer desired signal amplitude. This modulation is transferred to VCO V_i with filtering equal to $|\rho_{i,\ell}(S).CC|_{s=j\omega_{\delta\ell}}$. Once $\omega_{\delta\ell}$ is determined, the computation is similar to that of Section 4.6.1. The sequence of computations:

1) For each mixer, in turn, and for each spur type j, k ($1 \leq j \leq 7$, $1 \leq K \leq 8$) the spur frequencies $|j\omega_{siG} - K\omega_{osc}|$ are computed (for both lists of programmable elements) and compared with the corresponding desired mixer output frequency to obtain a set of frequency offsets.
2) A check is made for crossover spurs. If either of the spurs types $j\omega_{siG} + K\omega_{osc}$ or $|j\omega_{siG} - K\omega_{osc}|$ yield offsets of opposite sign for the alternate lists of programmable elements, a crossover spur occurs at some setting of the programmable elements. No filtering is provided for the crossover spur type at the worst case (crossover) frequency.

2.a) Because of the linear relation between component frequencies and programmable element values they may be obtained by an interpolation routine. Define $r = \omega_{\delta 2}/(\omega_{\delta 1} - \omega_{\delta 2})$ where $\omega_{\delta 1}$ and $\omega_{\delta 2}$ are the offsets for the two programmable element lists (NOTE: $\omega_{\delta 1}$ and $\omega_{\delta 2}$ have opposite signs). Then each VCO frequency at the setting of the crossover spur is computed from;

$$V_c = V_2 + (V_2 - V_1).r$$

where V_1 and V_2 are the VCO output frequencies for the two

* * * * * * * * * * * * * * * * * *

SPURIOUS PHASE MODULATION
******** ***** **********

PHASE COMPARATOR REFERENCE SPURS
***** ********** ********* *****

LOOP	COL	REF LEAKAGE	FILTERING TO OUTPUTS: 2	6	8
1	1	36.0	999.0	93.7	168.5
1	2	36.0	999.0	92.5	163.1
2	1	36.0	-19.8	71.7	145.6
2	2	36.0	-19.4	69.6	140.2
3	1	36.0	999.0	52.7	127.5
3	2	36.0	999.0	50.4	121.0
4	1	36.0	999.0	38.1	112.9
4	2	36.0	999.0	34.9	105.5
5	1	27.0	999.0	44.3	119.1
5	2	27.0	999.0	41.9	112.5
6	1	27.0	999.0	51.5	126.3
6	2	27.0	999.0	49.0	119.6
7	1	27.0	999.0	999.0	81.4
7	2	27.0	999.0	999.0	77.2
8	1	27.0	999.0	999.0	74.8
8	2	27.0	999.0	999.0	70.6

REF LEAKAGE COLUMN INDICATES DB BELOW KD

FILTERING COLUMN(S) INDICATE SYNTHESIZER FILTERING
BETWEEN LOOP I PHASE COMPARATOR AND VCO

SPUR LEVEL AT EACH OUTPUT VCO (DB BELOW 1 RADIAN)
DUE TO REFERENCE LEAKAGE GENERATED IN LOOP I
IS SUM OF REF LEAKAGE AND VCO FILTERING COLUMNS

IF ANY VCO FILTERING COLUMMN VALUE IS 999 THE VCO
DOES NOT RESPOND TO SIGNALS GENERATED AT PHASE COMPARATOR I

Figure 19. Spurious Phase Modulation Phase Comparator Reference Spurs Sample Printout

lists computed in 4.5.3. The programmable element, p, at crossover, has numerator and denominator given by

$$n_{pc} = n_{p2} + (n_{p2} - n_{p1})r$$

$$d_{pc} = d_{p2} + (d_{p2} - d_{p1}).r$$

where n_{p1}, n_{p2}, d_{p1}, d_{p2} are the integer values of the numerators and denominators of the pth programmable element in the two lists. n_{pc} and d_{pc} are rounded to the nearest integer.

2.b) A check is made to see which output frequencies vary with change of each programmable element. This has been determined in 4.5.1(4).

2.c) A sample printout for a crossover spur is given in Figure 20. The spur type (j, k) is given together with its spur phase modulation as generated at the mixer. The interpolated values of the numerator and denominator are printed for each programmable element. The interpolated frequency of each output VCO at the crossover is given for those programmable elements that affect the output VCO (otherwise a zero is printed). Thus, setting the programmable elements, with non-zero frequencies, for a given VCO, to the values indicated will result in the output VCO being set to its worst case (crossover) frequency.

3) For non-crossover spurs, the phase locked loops will provide filtering to the spur modulation generated at the mixers. The worst case frequency offset for each spur type j, k is determined as the smallest of the absolute values of the offsets computed in (1). To avoid extensive computation of large filter losses, it is assumed that whenever the worst case offset exceeds five times the largest phase comparator reference frequency (computed in Section 4.5.3), the loop filtering will be sufficiently great so that the spur j, k output is negligible and no printout is made.

3.a) For worst case offsets, ω_δ, less than five times the largest phase comparator reference frequency, S is set equal to $j\omega_\delta$ and the filtering to each output VCO is obtained from the absolute value of the appropriate element of the matrix $\rho(S)$.CC.

3.b) A sample printout for non-crossover spurs is given in Figure 20 indicating printout of spur type, the column (list) number for the worst case spur, worst case spur frequency, the phase modulation generated at the mixer output (expressed in db below the desired mixer output), and the filtering to each output.

4) If the synthesizer includes a mixer which generates spurs that do not vary in frequency with interchange of programmable element lists, the spurs are identified as fixed frequency spurs.

lists computed in 4.5.3. The programmable element, p, at crossover, has numerator and denominator given by

$$n_{pc} = n_{p2} + (n_{p2} - n_{p1})r$$

$$d_{pc} = d_{p2} + (d_{p2} - d_{p1}).r$$

where n_{p1}, n_{p2}, d_{p1}, d_{p2} are the integer values of the numerators and denominators of the pth programmable element in the two lists. n_{pc} and d_{pc} are rounded to the nearest integer.

2.b) A check is made to see which output frequencies vary with change of each programmable element. This has been determined in 4.5.1(4).

2.c) A sample printout for a crossover spur is given in Figure 20. The spur type (j, k) is given together with its spur phase modulation as generated at the mixer. The interpolated values of the numerator and denominator are printed for each programmable element. The interpolated frequency of each output VCO at the crossover is given for those programmable elements that affect the output VCO (otherwise a zero is printed). Thus, setting the programmable elements, with non-zero frequencies, for a given VCO, to the values indicated will result in the output VCO being set to its worst case (crossover) frequency.

3) For non-crossover spurs, the phase locked loops will provide filtering to the spur modulation generated at the mixers. The worst case frequency offset for each spur type j, k is determined as the smallest of the absolute values of the offsets computed in (1). To avoid extensive computation of large filter losses, it is assumed that whenever the worst case offset exceeds five times the largest phase comparator reference frequency (computed in Section 4.5.3), the loop filtering will be sufficiently great so that the spur j, k output is negligible and no printout is made.

3.a) For worst case offsets, ω_δ, less than five times the largest phase comparator reference frequency, S is set equal to $j\omega_\delta$ and the filtering to each output VCO is obtained from the absolute value of the appropriate element of the matrix $\rho(S)$.CC.

3.b) A sample printout for non-crossover spurs is given in Figure 20 indicating printout of spur type, the column (list) number for the worst case spur, worst case spur frequency, the phase modulation generated at the mixer output (expressed in db below the desired mixer output), and the filtering to each output.

4) If the synthesizer includes a mixer which generates spurs that do not vary in frequency with interchange of programmable element lists, the spurs are identified as fixed frequency spurs.

```
SPURS, MIXER NUMBER  4
****** ***** ****** **

CROSSOVER SPUR
********* ****
J K COL            SPUR(DB)
6 7 0              105.0
PROGRAMMABLE ELEMENT VALUES AT CROSSOVER FREQUENCIES
                     <---------------CROSSOVER FREQUENCIES--------------->

NO.    NUM    DEN/OUT:   2           6           8
 1      1      18 0.00000E 0   .12048E 3   .10848E 4
 2      1      21   .35143E 2   .12048E 3   .10848E 4
 3      1      20 0.00000E 0   .12048E 3   .10848E 4
 4      1      19 0.00000E 0   .12048E 3   .10848E 4
 5      1      20 0.00000E 0   .12048E 3   .10848E 4
 6      1     193 0.00000E 0 0.00000E 0   .10848E 4
CROSSOVER SPUR
********* ****
J K COL            SPUR(DB)
7 8 0              108.0
PROGRAMMABLE ELEMENT VALUES AT CROSSOVER FREQUENCIES
                     <---------------CROSSOVER FREQUENCIES--------------->

NO.    NUM    DEN/OUT:   2           6           8
 1      1      18 0.00000E 0   .11854E 3   .10654E 4
 2      1      21   .84962E 2   .11854E 3   .10654E 4
 3      1      20 0.00000E 0   .11854E 3   .10654E 4
 4      1      19 0.00000E 0   .11854E 3   .10654E 4
 5      1      20 0.00000E 0   .11854E 3   .10654E 4
 6      1     189 0.00000E 0 0.00000E 0   .10654E 4
SPURS, MIXER NUMBER  5
****** ***** ****** **
```

A) Crossover Spurs

```
SPURS, MIXER NUMBER  8
****** ***** ****** **

NON-CROSSOVER SPUR
************* ****

                             <-------- FILTERING TO OUTPUTS(DB)-------->
J K COL    DELW     SPUR        2          6          8
6 7 1    .1000E 1  105.0      999.0       18.6       51.1
```

B) Noncrossover Spur

```
JK = SPUR TYPE

FOR CROSSOVER SPUR:
ZERO VALUE FOR OUTPUT FREQUENCY INDICATES CORRESPONDING
PROGRAMMABLE ELEMENT DOES NOT CONTRIBUTE
TO CROSSOVER SPUR

SPUR(DB)=SPURIOUS MODULATION(DB BELOW 1 RADIAN)

FOR NON-CROSSOVER SPUR:
SPUR=DB BELOW MIXER OUTPUT LEVEL

VALUE UNDER OUTPUT VCO=FILTERING(DB) FOR SPUR
MODULATING FREQUENCY DELW
IF VALUE INDICATED IS 999 TRANSMISSION TO
OUTPUT VCO IS NEGLIGIBLE

SPUR MODULATION ON OUTPUT VCO(DB BELOW 1 RADIAN)
IS SUM OF SPUR AND FILTERING VALUES
```

Figure 20. Spurious Phase Modulation Mixer Spurs Sample Printout

4.7 NOISE PHASE MODULATION

If the response to the question in Section 4.1.2 relative to noise modulation performance is <u>no</u> the program advances to Section 4.8.

If <u>yes</u> noise phase modulation performance due to VCO and circuit noise is computed.

Noise phase modulation (expressed as dbrad/HZ where dbrad = decibels below 1 radian) is computed for the spectrum for which modulating noise for all VCO's has been defined in the data entry process (Section 4.2.1.3(c)). The noise phase modulation spectrum is computed for VCO noise, circuit noise and combined noise. The sequence of computations:

1) Let $F1_i$ $(1 \leq i \leq L)$ be the set of minimum frequencies for the defined noise modulation spectra of the L VCO's; let $F2_i$ be the set of L VCO maximum defined noise modulation frequencies. The greatest $F1_i$ and smallest $F2_i$ is determined and output VCO noise spectra are computed for the band $(F1_i)_{max}$ to $(F2_i)_{min}$ at these frequencies and at half decade increments between them.
2) At each computed frequency, ω, the matrices $R(S)$, $\rho(S)$ and $\rho(S).CC$ are computed for $S=j\omega$.

4.7.1 <u>VCO Noise</u>

3.a) At each computed frequency, each VCO noise spectrum level (in dbrad/HZ) is determined by linear interpolation (db vs log ω) of the VCO noise spectrum at the nearest defined frequencies below and above the computed frequency.

3.b) The output noise spectra at ω, due to VCO noise are obtained by converting the computed results from (3.a) from decibels to power ratios, multiplying the results by the magnitude squared of the appropriate term of the matrix, $R(j\omega)$, adding the contributions to each output and converting each result to decibels. The computations are made for both lists of programmable elements.

4.7.2 <u>Circuit Noise</u>

4.7.2.1 <u>Phase Comparator Noise</u>

4.a) Circuit noise computed consists of phase comparator and mixer noise. The equivalent noise level ($volt^2$/HZ) at each phase comparator, taking into account the gain (at $S=j\omega$) and noise figure of the loop filter is:

$$S_D(\omega) = kT.F.r_o/K_D^2$$

where

$kT = 4x10^{-21}$ watts/HZ

r_o = phase comparator output resistance

K_D = phase comparator gain constant (volt/rad)

4.b) The contribution of each phase comparator to each output is obtained by multiplying each input noise by the magnitude squared of the appropriate element of the matrix, $\rho(j\omega)$. The contributions to each output are added. Computations are made for both lists.

4.7.2.2 Mixer Noise

5.a) Noise (rad^2/HZ) generated at each mixer is computed in accordance with: $S_{QM} = KT/P_M$

where P_M = Mixer output power

Mixer noise is dependent on the mixer output level, determined from the input data (input signal level and mixer conversion loss).

5.b) The contribution of each mixer to each output is obtained by multiplying each mixer noise output by the magnitude squared of the appropriate element of the matrix $\rho(j\omega)$ CC. The contributions to each output are added and summed with corresponding terms in 4.b to obtain total circuit noise at each output. The results are converted to decibels for printout. Computations are made for both lists.

4.7.3 Total Noise

6) Total noise at each output (for both lists) is obtained by adding the VCO noise (from 3.b) and circuit noise (from 5.b) prior to conversion to decibels. The sum is converted to decibels for printout in accordance with the sample of Figure 21.

4.8 ACQUISITION

If the response to the question of Section 4.1.2 relative to computation of acquisition characteristics is no the program terminates.

If yes a solution is computed of the set of loop differential equations.

4.8.1 Initial Conditions

The solution is based on two sets of initial conditions:

a) The initial frequency offset, ω_Δ, of each VCO. This is dependent on the resettability of each VCO and the statement of the acquisition problem to be solved.

b) The initial phase of each signal - These are generated by a random number generator routine based on the entry of a key number which may be any five digit integer. If the same key number is used for successive computer runs, the initial signal phases will be identical; otherwise, a new set of random initial phases will be generated. The user is requested:

* VCO PHASES DETERMINED BY RANDOM NUMBER GENERATOR

* ENTER 5 DIGIT INTEGER TO KEY RANDOM NUMBER GENERATOR

If the number of phase locked loops is six or less, the user is requested:

* ENTER INITIAL FREQUENCY OFFSET (MHZ) FOR EACH VCO

If the number of phase locked loops exceeds six:

* ENTER INITIAL FREQUENCY OFFSETS FOR FIRST 6 VCO'S

* ENTER INITIAL FREQUENCY OFFSETS FOR REMAINING VCO'S

Initial conditions are computed for loop parameters from the initial signal phases and frequency offsets.

* * * * * * * * * * * * * * * * * *

NOISE PHASE MODULATION
***** ***** ***********

PHASE NOISE SPECTRUM,VCO 2 (COLUMN 1)

FREQ	OSC	CIRCUIT	TOTAL
.100E-02	95.4	136.7	95.4
.316E-02	100.4	135.7	100.4
.100E-01	105.3	136.8	105.3
.316E-01	110.1	136.8	110.1
.100E+00	115.0	137.5	115.0
.316E+00	115.2	141.3	115.2
.100E+01	120.1	149.6	120.1
.316E+01	120.0	159.3	120.0
.100E+02	120.0	169.3	120.0

PHASE NOISE SPECTRUM,VCO 2 (COLUMN 2)

FREQ	OSC	CIRCUIT	TOTAL
.100E-02	101.1	141.1	101.1
.316E-02	106.1	141.1	106.1
.100E-01	111.1	141.1	111.1
.316E-01	115.8	141.1	115.8
.100E+00	120.0	141.3	119.9
.316E+00	117.4	142.8	117.4
.100E+01	120.3	143.7	120.3
.316E+01	119.9	157.9	119.9
.100E+02	120.0	167.8	120.0

PHASE NOISE SPECTRUM,VCO 6 (COLUMN 1)

FREQ	OSC	CIRCUIT	TOTAL
.100E-02	81.6	137.2	81.6
.316E-02	73.1	137.1	73.1
.100E-01	67.1	136.5	67.1
.316E-01	68.2	139.6	68.2
.100E+00	83.7	149.7	83.7
.316E+00	103.2	160.3	103.2
.100E+01	119.2	169.5	119.2
.316E+01	119.9	183.0	119.9
.100E+02	120.0	999.0	120.0

PHASE NOISE SPECTRUM,VCO 6 (COLUMN 2)

FREQ	OSC	CIRCUIT	TOTAL
.100E-02	82.3	142.0	82.3
.316E-02	74.8	141.9	74.8
.100E-01	69.6	141.4	69.6
.316E-01	69.4	142.7	69.4
.100E+00	84.3	152.2	84.3
.316E+00	102.6	161.6	102.6
.100E+01	118.7	165.6	118.7
.316E+01	119.9	174.3	119.9
.100E+02	120.0	189.9	120.0

PHASE NOISE SPECTRUM,VCO 8 (COLUMN 1)

FREQ	OSC	CIRCUIT	TOTAL
.100E-02	40.1	128.9	40.1
.316E-02	45.3	129.1	45.3
.100E-01	51.8	131.0	51.8
.316E-01	63.7	142.1	63.7
.100E+00	80.6	162.9	80.6
.316E+00	95.1	178.0	95.1
.100E+01	110.0	195.2	110.0
.316E+01	115.0	999.0	115.0
.100E+02	120.0	999.0	120.0

PHASE NOISE SPECTRUM,VCO 8 (COLUMN 2)

FREQ	OSC	CIRCUIT	TOTAL
.100E-02	43.6	133.8	43.6
.316E-02	48.6	133.8	48.6
.100E-01	53.9	134.7	53.9
.316E-01	63.8	144.0	63.8
.100E+00	80.5	164.3	80.5
.316E+00	95.1	173.4	95.1
.100E+01	110.0	191.9	110.0
.316E+01	115.0	999.0	115.0
.100E+02	120.0	999.0	120.0

VALUES INDICATED ARE (DB BELOW 1 RADIAN)/HZ

Figure 21. Noise Phase Modulation Sample Printout

4.8.2 Choice of Integration Increment and Number of Increments

The recursive solution is dependent on a choice of integration increment, δ, sufficiently small so that trapezoidal approximation is valid. If the increment chosen is too small, the number of increments required to compute the acquisition characteristic for a given time block, becomes very large and the accuracy degrades due to computational round-off errors. It is not feasible to provide an automatic selection of integration increment, valid over the range of synthesizer loop dynamics encountered in the use of the synthesizer computer program so that the choice is left to the user.

To assist the user in choosing the integration increment, each loop is considered separately. If the loop filter for the ith loop has a network function $F_i(S) = n_i(S)/d_i(S)$, the open loop gain $G_i(s) = K_D K_V F_i(S)/NS$ and the closed loop gain:

$$H_i(S)=G_i/(1+G_i)=(K_D K_V/B)\ n_i/(S.d_i + (K_D K_V/N)n_i)$$

1/N is obtained from the i,i term of the matrix AA. The characteristic polynomial $sd_i + (K_D K_V/N)n_i$ is generated from the poles, zeros and gain constants of $F_i(S)$ and factored to determine closed loop poles.

Parallel computations are made for both lists of programmable elements and the closed loop pole with the most negative real part is selected as determining the high frequency dynamics of the synthesizer. The fastest time constant is the reciprocal of the most negative real part. The suggested integration increment is 1/20 of the fastest time constant.

* OPTIONS AVAILABLE TO USE A DIFFERENT COMPUTED INTEGRATION TIME INCREMENT

If the root finding process required to factor the characteristic polynomials does not converge a warning is printed. In this case a trial and error method for selecting the integration increment is suggested.

The user is requested:

* ENTER INTEGRATION TIME INCREMENT (MICROSECONDS)

* ENTER NUMBER OF INTEGRATION INCREMENTS

The user is offered an option to print the computations at selected increments:

* OPTION TO PRINT EVERY NTH DATA POINT; ENTER N

The trial and error method consists of selecting a deliberately coarse time increment and a small number of increments (e.g. 100). N is selected as 1.

The acquisition characteristic is computed and the program is rerun, choosing an increment half as large, doubling the number of increments and letting N=2. The results are compared with the previous run. If the results are acceptably similar the original time increment was suitable. The process is continued until essentially similar results obtain from successive runs. The solution is then continued for an extended number of increments to determine the acquisition characteristic.

NOTE: The trial and error method may also be employed when a suggested integration increment is provided without warning of failure of the root finding routine. The initial time increment entered will then be a value much coarser than the suggested value.

4.8.3 Recursive Solution of Loop Differential Equations

The recursive solution is computed employing a predictor-corrector technique. Every Nth increment the phase and frequency errors at each output VCO, Θ_{ve} and $\dot{\Theta}_{ve}$ are printed for both lists of programmable elements.

After the requested number of increments have been computed, the user may continue the solution:

* CONTINUE SOLUTION?

If no the program terminates.

If yes the program returns to:

* OPTIONS AVAILABLE TO USE A DIFFERENT INTEGRATION TIME INCREMENT

* ENTER INTEGRATION TIME INCREMENT (MICROSECONDS)

* ENTER NUMBER OF INTEGRATION INCREMENTS

* OPTION TO PRINT EVERY NTH DATA POINT; ENTER N

The integration continues for the number of integration increments indicated by the user. (It is noted that he may change the time increment and the selection of data points for printout.) The user is again asked:

* CONTINUE SOLUTION?

The user may continue or terminate the solution as before. A sample printout is given in Figure 22.

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ADVANCED RECEIVER MODELING METHODS.(U)

SEP 77 S FAST F33615-75-C-1265

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2 OF 2

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END

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```
ACQUISITION CHARACTERISTICS
*********** ***************
WARNING! ROOTS ROUTINE FAILED TO CONVERGE
WARNING! ROOTS ROUTINE FAILED TO CONVERGE
VCO PHASES DETERMINED BY RANDOM NUMBER GENERATOR
ENTER 5 DIGIT INTEGER TO KEY RANDOM NUMBER GENERATOR
?63517
ENTER INITIAL FREQUENCY OFFSET(MHZ) FOR EACH VCO
ENTER INITIAL FREQUENCY OFFSETS FOR FIRST 6 VCO"S
?0.,-5.E-3,0.,0.,0.,-5.E-3
ENTER INITIAL FREQUENCY OFFSETS FOR REMAINING VCO"S
?0.,-5.E-3
                 STEADY STATE PHASE ERROR              BIAS ERROR
LOOP             COL. 1                 COL. 2              DET. BIAS
 1            0.                     0.                   .158489E-01
 2            0.                     0.                   .158489E-01
 3            0.                     0.                   .158489E-01
 4            0.                     0.                   .158489E-01
 5            0.                     0.                   .100000E-01
 6            0.                     0.                   .100000E-01
 7            0.                     0.                   .100000E-01
 8            0.                     0.                   .100000E-01

INITIAL CONDITIONS

                        PHASE ERROR                  FREQUENCY ERROR
    T         OUT   COLUMN 1      COLUMN 2        COLUMN 1      COLUMN 2

    .           2    .13850E+01    .13850E+01    -.44453E+00   -.85359E+00
                6   -.13823E+01   -.13823E+01    -.54001E-01   -.54001E-01
                8    .30159E+01    .30159E+01    -.26952E-01   -.26952E-01
COMPUTED INTEGATION TIME INCREMENT:      .143449E-02
OPTIONS AVAILABLE TO USE A DIFFERENT INTEGRATION TIME INCREMENT
CHANGE INTEGRATION TIME INCREMENT?
?YES
ENTER INTEGRATION TIME INCREMENT(MICROSECONDS)
?.1
ENTER NUMBER OF INTEGRATION INCREMENTS
?20
OPTION TO PRINT EVERY NTH DATA POINT:ENTER N
?1
                        PHASE ERROR                  FREQUENCY ERROR
    T         OUT   COLUMN 1      COLUMN 2        COLUMN 1      COLUMN 2
.1000E+00       2    .16260E+01    .14242E+01    -.38506E+00   -.64783E+00
                6   -.14167E+01   -.14120E+01    -.56881E-01   -.50413E-01
                8    .29990E+01    .29990E+01    -.26942E-01   -.26756E-01
.2000E+00       2    .14016E+01    .10746E+01    -.33354E+00   -.49166E+00
                6   -.14478E+01   -.14326E+01    -.45072E-01   -.24972E-01
                8    .29821E+01    .29823E+01    -.26904E-01   -.26461E-01
.3000E+00       2    .12073E+01    .80919E+00    -.28890E+00   -.37313E+00
                6   -.14702E+01   -.14392E+01    -.29105E-01   -.25723E-02
                8    .29652E+01    .29658E+01    -.26786E-01   -.25999E-01
.4000E+00       2    .10390E+01    .60779E+00    -.25024E+00   -.28317E+00
                6   -.14830E+01   -.14348E+01    -.14179E-01    .12793E-01
                8    .29434E+01    .29496E+01    -.26571E-01   -.25367E-01
.5000E+00       2    .89319E+00    .45495E+00    -.21675E+00   -.21489E+00
                6   -.14875E+01   -.14229E+01    -.19430E-02    .22718E-01
                8    .29318E+01    .29339E+01    -.26259E-01   -.24581E-01
.6000E+00       2    .76691E+00    .33897E+00    -.18774E+00   -.16307E+00
                6   -.14853E+01   -.14062E+01     .75466E-02    .29124E-01
                8    .29154E+01    .29188E+01    -.25851E-01   -.23659E-01
.7000E+00       2    .65754E+00    .25095E+00    -.16260E+00   -.12374E+00
                6   -.14780E+01   -.13864E+01     .14746E-01    .33338E-01
```

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Figure 22. Acquisition Characteristics

.1000E+00	2	.16260E+01	.14242E+01	-.38506E+00	-.64783E+00
	6	-.14167E+01	-.14120E+01	-.56881E-01	-.50413E-01
	8	.29990E+01	.29990E+01	-.26942E-01	-.26756E-01
.2000E+00	2	.14016E+01	.10746E+01	-.33354E+00	-.49166E+00
	6	-.14478E+01	-.14326E+01	-.45072E-01	-.24972E-01
	8	.29821E+01	.29823E+01	-.26904E-01	-.26461E-01
.3000E+00	2	.12073E+01	.80919E+00	-.28890E+00	-.37313E+00
	6	-.14702E+01	-.14392E+01	-.29105E-01	-.25723E-02
	8	.29652E+01	.29658E+01	-.26786E-01	-.25999E-01
.4000E+00	2	.10390E+01	.60779E+00	-.25024E+00	-.28317E+00
	6	-.14830E+01	-.14348E+01	-.14179E-01	.12793E-01
	8	.29434E+01	.29496E+01	-.26571E-01	-.25367E-01
.5000E+00	2	.89319E+00	.45495E+00	-.21675E+00	-.21489E+00
	6	-.14875E+01	-.14229E+01	-.19430E-02	.22718E-01
	8	.29318E+01	.29339E+01	-.26259E-01	-.24581E-01
.6000E+00	2	.76691E+00	.33897E+00	-.18774E+00	-.16307E+00
	6	-.14853E+01	-.14062E+01	.75466E-02	.29124E-01
	8	.29154E+01	.29188E+01	-.25851E-01	-.23659E-01
.7000E+00	2	.65754E+00	.25095E+00	-.16260E+00	-.12374E+00
	6	-.14780E+01	-.13864E+01	.14746E-01	.33338E-01
	8	.28993E+01	.29042E+01	-.25353E-01	-.22617E-01
.8000E+00	2	.56280E+00	.18416E+00	-.14083E+00	-.93893E-01
	6	-.14668E+01	-.13644E+01	.20181E-01	.36176E-01
	8	.28836E+01	.28904E+01	-.24771E-01	-.21472E-01
.9000E+00	2	.48075E+00	.13349E+00	-.12197E+00	-.71238E-01
	6	-.14526E+01	-.13409E+01	.24298E-01	.38126E-01
	8	.23682E+01	.28773E+01	-.24108E-01	-.20238E-01
.1000E+01	2	.40969E+00	.95039E-01	-.10564E+00	-.54043E-01
	6	-.14363E+01	-.13165E+01	.27440E-01	.39486E-01
	8	.28533E+01	.28650E+01	-.23373E-01	-.18931E-01
.1100E+01	2	.34815E+00	.65873E-01	-.91483E-01	-.40993E-01
	6	-.14182E+01	-.12913E+01	.29860E-01	.40436E-01
	8	.28339E+01	.28535E+01	-.22570E-01	-.17565E-01
.1200E+01	2	.29486E+00	.43750E-01	-.79223E-01	-.31088E-01
	6	-.13988E+01	-.12657E+01	.31740E-01	.41094E-01
	8	.28250E+01	.28429E+01	-.21707E-01	-.16152E-01
.1300E+01	2	.24870E+00	.26974E-01	-.68603E-01	-.23571E-01
	6	-.13783E+01	-.12397E+01	.33212E-01	.41532E-01
	8	.28116E+01	.28332E+01	-.20789E-01	-.14705E-01
.1400E+01	2	.20874E+00	.14256E-01	-.59403E-01	-.17865E-01
	6	-.13570E+01	-.12135E+01	.34370E-01	.41803E-01
	8	.27989E+01	.28245E+01	-.19824E-01	-.13235E-01
.1500E+01	2	.17413E+00	.46173E-02	-.51433E-01	-.13535E-01
	6	-.13351E+01	-.11872E+01	.35284E-01	.41939E-01
	8	.27867E+01	.28166E+01	-.18816E-01	-.11755E-01
.1600E+01	2	.14417E+00	-.26842E-02	-.44530E-01	-.10249E-01
	6	-.13127E+01	-.11608E+01	.36003E-01	.41964E-01
	8	.27752E+01	.28097E+01	-.17774E-01	-.10273E-01
.1700E+01	2	.11823E+00	-.82119E-02	-.38549E-01	-.77542E-02
	6	-.12899E+01	-.11345E+01	.36566E-01	.41897E-01
	8	.27644E+01	.28037E+01	-.16703E-01	-.87984E-02
.1800E+01	2	.95776E-01	-.12393E-01	-.33369E-01	-.58612E-02
	6	-.12668E+01	-.11082E+01	.36999E-01	.41748E-01
	8	.27543E+01	.27987E+01	-.15609E-01	-.73396E-02
.1900E+01	2	.76338E-01	-.15553E-01	-.28881E-01	-.44245E-02
	6	-.12434E+01	-.10820E+01	.37325E-01	.41528E-01
	8	.27448E+01	.27945E+01	-.14498E-01	-.59037E-02
.2000E+01	2	.59515E-01	-.17937E-01	-.24994E-01	-.33341E-02
	6	-.12199E+01	-.10560E+01	.37559E-01	.41245E-01
	8	.27361E+01	.27912E+01	-.13375E-01	-.44969E-02

```
CONTINUE SOLUTION?
?YES
 CHANGE INTEGRATION TIME INCREMENT?
?NO
 ENTER NUMBER OF INTEGRATION INCREMENTS
?180
 OPTION TO PRINT EVERY NTH DATA POINT:ENTER N
?10
```

		PHASE ERROR		FREQUENCY ERROR	
T	OUT	COLUMN 1	COLUMN 2	COLUMN 1	COLUMN 2
.3000E+01	2	-.22956E-01	-.24565E-01	-.58074E-02	-.12001E-03
	6	-.98424E+00	-.81157E+00	.36676E-01	.36005E-01
	8	.26870E+01	.28022E+01	-.24629E-02	.71763E-02

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	6	-.13351E+01	-.11872E+01	.35284E-01	.41939E-01
	8	.27867E+01	.28166E+01	-.18816E-01	-.11755E-01
.1600E+01	2	.14417E+00	-.26842E-02	-.44530E-01	-.10249E-01
	6	-.13127E+01	-.11608E+01	.36003E-01	.41964E-01
	8	.27752E+01	.28097E+01	-.17774E-01	-.10273E-01
.1700E+01	2	.11823E+00	-.82119E-02	-.38549E-01	-.77542E-02
	6	-.12899E+01	-.11345E+01	.36566E-01	.41897E-01
	8	.27644E+01	.28037E+01	-.16703E-01	-.87984E-02
.1800E+01	2	.95776E-01	-.12393E-01	-.33369E-01	-.58612E-02
	6	-.12668E+01	-.11082E+01	.36999E-01	.41748E-01
	8	.27543E+01	.27987E+01	-.15609E-01	-.73396E-02
.1900E+01	2	.76338E-01	-.15553E-01	-.28881E-01	-.44245E-02
	6	-.12434E+01	-.10820E+01	.37325E-01	.41528E-01
	8	.27448E+01	.27945E+01	-.14498E-01	-.59037E-02
.2000E+01	2	.59515E-01	-.17937E-01	-.24994E-01	-.33341E-02
	6	-.12199E+01	-.10560E+01	.37559E-01	.41245E-01
	8	.27361E+01	.27912E+01	-.13375E-01	-.44969E-02

```
 CONTINUE SOLUTION?
?YES
 CHANGE INTEGRATION TIME INCREMENT?
?NO
 ENTER NUMBER OF INTEGRATION INCREMENTS
?180
 OPTION TO PRINT EVERY NTH DATA POINT;ENTER N
?10
```

		PHASE ERROR		FREQUENCY ERROR	
T	OUT	COLUMN 1	COLUMN 2	COLUMN 1	COLUMN 2
.3000E+01	2	-.22956E-01	-.24565E-01	-.58074E-02	-.12001E-03
	6	-.98424E+00	-.81157E+00	.36676E-01	.36005E-01
	8	.26870E+01	.28022E+01	-.24629E-02	.71763E-02
.4000E+01	2	-.41743E-01	-.24460E-01	-.12449E-02	.81797E-04
	6	-.76598E+00	-.60776E+00	.32448E-01	.28809E-01
	8	.27000E+01	.28712E+01	.61027E-02	.14066E-01
.5000E+01	2	-.45394E-01	-.23940E-01	-.16227E-03	.92589E-04
	6	-.57963E+00	-.44906E+00	.25778E-01	.21894E-01
	8	.27575E+01	.29716E+01	.11755E-01	.17451E-01
.6000E+01	2	-.45462E-01	-.23405E-01	.92320E-04	.91311E-04
	6	-.42984E+00	-.33027E+00	.20988E-01	.16165E-01
	8	.28430E+01	.30864E+01	.15148E-01	.18880E-01
.7000E+01	2	-.44695E-01	-.22881E-01	.14994E-03	.89312E-04
	6	-.31459E+00	-.24330E+00	.15867E-01	.11744E-01
	8	.29448E+01	.32068E+01	.17103E-01	.19375E-01
.8000E+01	2	-.43748E-01	-.22363E-01	.16076E-03	.87310E-04
	6	-.22854E+00	-.13043E+00	.11707E-01	.84535E-02
	8	.30561E+01	.33290E+01	.18238E-01	.19503E-01

3

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SECTION V

MIXER CATALOG COMPUTER PROGRAM, SPURS

Characterization of the performance of a mixer relative to its generation of spurious outputs requires an extensive amount of data (refer to Section 3.11). To avoid entry of this information for each mixer encountered in using the receiver signal path and synthesizer computer programs, the mixer data is stored in a separate computer file that is accessed by these programs.

The mixer catalog computer program is used to generate, correct and extend the mixer data files. The management of mixer data files requires accomplishment of three tasks:

(a) Initial generation of a new mixer catalog
(b) Access to data on file
(c) Data correction and extension

5.1 GENERATION OF NEW MIXER CATALOG

The user is asked:

* HAS A MIXER CATALOG FILE BEEN OPENED PREVIOUSLY?

If yes a catalog of data on file is printed in accordance with Figure 23. Each mixer is characterized by a three word descriptor. (Each word may contain as many as 10 alphanumeric characters.) The first word is used to identify the manufacturer; the second is his part number; the third is the local oscillator power level (in dbm). The program advances to Section 5.2.

If no a catalog is printed in accordance with Figure 23 with "blank" written for the descriptor words corresponding to the manufacturer's name and part number and 99 written for the power level. The program advances to Section 5.3.

Mixer Catalog

```
 HAS A MIXER CATALOG FILE BEEN OPENED PREVIOUSLY?
 ANSWER: YES OR NO
?YES
MIXER       MANUF        CAT. NO.   P-OSC(DBM)
    1      RELCOM        M14A          7.
    2      RELCOM        M9E           27.
    3      RELCOM        M1            7.
    4      BLANK         BLANK           99
    5      BLANK         BLANK           99
    6      BLANK         BLANK           99
```

Figure 23. Mixer Catalog

5.2 DATA ACCESS

The user is advised:

* MIXER SPUR PRODUCT DATA IS TABULATED IN TWO WAYS:
* SPUR PRODUCT INTERCEPTS (TABLE 0) OR
* SPUR PRODUCT CONVERSION LOSS FOR GIVEN SIGNAL LEVEL (TABLE 1)

NOTE: Table 0 corresponds to specification of $P_{j,k}$ for spur product type j,k; Table 1 corresponds to specification of $R_{j,k}$ and P_a (refer to Section 3.11).

Mixer spur data is stored in the data file in the form of $P_{j,k}$ for each j,k ($0 \leq j < 7$; $0 \leq K \leq 8$) since $P_{j,k}$ is a characteristic of the mixer independent of signal level, P_a. If a tabulation of $R_{j,k}$ is desired for a given P_a, it is computed from (17) for $j \neq 1$. For $j=1$, $P_{j,k}$ is chosen (arbitrarily) $P_{j,k} = R_{j,k}$.

The user is requested:
* PRINT MIXER SPUR TABLE? ANSWER: YES OR NO
If no the program advances to Section 5.3.
If yes the user is requested:
* ENTER ONE MIXER NUMBER FROM CATALOG AND
* SPUR DATA TABLE DESIRED
* EXAMPLE: 6,0

The mixer number entered its catalog descriptor and mixer conversion loss are printed in accordance with the printout of Figure 24.

If Table 0 is requested a printout of $P_{j,k}$ vs j,k is given in accordance with Figure 24(a).

If Table 1 is requested, the user is requested:
* SPECIFY MIXER SIGNAL INPUT LEVEL

A printout of $R_{j,k}$ vs j,k is given in accordance with Figure 24(b) computed from P_a and $P_{j,k}$.

Upon conclusion of the printout the user is asked:
* PRINT ANOTHER MIXER SPUR TABLE?
* ANSWER YES OR NO
If no the program advances to Section 5.3.
If yes the program returns to the question:
* ENTER ONE MIXER NUMBER FROM CATALOG AND
* SPUR DATA TABLE DESIRED.

The process is repeated until the user answers no to the question: * PRINT ANOTHER MIXER SPUR TABLE.

5.3 DATA ENTRY AND UPDATE

The user is advised:
* OPTIONS AVAILABLE TO ENTER A NEW MIXER INTO
* CATALOG OR TO CHANGE DATA ALREADY IN CATALOG

5.3.1 New Mixer Data Entry

The user is asked:
* ENTER NEW MIXER? ANSWER: YES OR NO
If no the program advances to Section 5.3.2.
If yes the user is requested:
* ENTER MIXER NUMBER
If the mixer number entered is the integer I, the user is requested:
* ENTER DESCRIPTOR FOR MIXER NUMBER I
* ENTER: MANUFACTURER, CATALOG NO., OSC LEVEL (DBM)
* ENTER 10 CHARACTERS FOR EACH FIELD, BLANK FILLING IF NEEDED.

MIXER SPUR PRODUCT DATA IS TABULATED IN TWO WAYS:
SPUR PRODUCT INTERCEPTS (TABLE 0) OR
SPUR PROD. CONVERSION LOSS FOR GIVEN SIGNAL LEVEL(TABLE 1)
PRINT MIXER SPUR TABLE? ANSWER: YES OR NO
?YES
ENTER ONE MIXER NUMBER FROM CATALOG AND
SPUR DATA TABLE DESIRED
EXAMPLE: 6,0
?3,0

MIXER	MANUF	CAT. NO.	P-OSC(DBM)
3	RELCOM	M1	7.

CONVERSION LOSS= 7.5DB
SPUR TABLE 0

J/K	0	1	2	3	4	5	6	7	8
0	99.0	-36.0	-45.0	-49.0	-60.0	-51.0	-63.0	-59.0	-61.0
1	24.0	0.0	35.0	13.0	40.0	24.0	45.0	28.0	49.0
2	63.0	63.0	64.0	60.0	61.0	54.0	59.0	54.0	59.0
3	23.5	22.0	24.5	15.0	28.5	13.5	27.0	12.0	27.0
4	18.7	20.0	18.7	19.3	19.3	18.3	18.7	18.3	20.0
5	12.5	10.0	12.5	7.7	12.5	7.0	12.5	6.2	12.0
6	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
7	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

a) Spur Table 0

PRINT ANOTHER MIXER SPUR TABLE?
ANSWER: YES OR NO
?YES
ENTER ONE MIXER NUMBER FROM CATALOG AND
SPUR DATA TABLE DESIRED
EXAMPLE: 6,0
?3,1

MIXER	MANUF	CAT. NO.	P-OSC(DBM)
3	RELCOM	M1	7.

CONVERSION LOSS= 7.5DB
SPECIFY MIXER SIGNAL INPUT LEVEL
?-10.
SPUR TABLE 1

J/K	0	1	2	3	4	5	6	7	8
0	99.0	26.0	35.0	39.0	50.0	41.0	53.0	49.0	51.0
1	24.0	0.0	35.0	13.0	40.0	24.0	45.0	28.0	49.0
2	73.0	73.0	74.0	70.0	71.0	64.0	69.0	64.0	69.0
3	67.0	64.0	69.0	50.0	77.0	47.0	74.0	44.0	74.0
4	86.1	90.0	86.1	87.9	87.9	84.9	86.1	84.9	90.0
5	90.0	80.0	90.0	70.8	90.0	68.0	90.0	64.8	88.0
6	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
7	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0

PRINT ANOTHER MIXER SPUR TABLE?
ANSWER: YES OR NO
?NO

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b) Spur Table 1

Figure 24. Spur Product Tables

The user is assisted by a 30 space printout for entry of the alphanumeric descriptor. An example is given:

```
*          123456789012345678901234567890
*     EXAMPLE:RELCOM    MID       17
*     123456789012345678901234567890
```

The user enters the mixer descriptor and is then requested:

* INPUT: MIXER CONVERSION LOSS (DB)

The user is then advised:

* MIXER SPUR PRODUCT DATA CAN BE ENTERED IN TWO WAYS:
* SPUR PRODUCT INTERCEPTS (TABLE 0) OR
* SPUR PROD. LOSS FOR GIVEN SIGNAL LEVEL (TABLE 1)
* ENTER DESIRED SPUR TABLE NUMBER (ANSWER 0 OR 1)

If the response to the question on spur table number is 0, the user is asked to enter the values of $P_{j,k}$ one row at a time for $0 \leq j \leq 7$:

* ENTER ROW j OF SPUR PRODUCT INTERCEPT MATRIX
* ENTER 9 VALUES (FOR k=0 to k=8)
* ENTER 99 FOR ANY UNKNOWN VALUES
* EXAMPLE: 63., 58., 65., 60., 65., 55., 64., 99, 99

If the response is 1, the user is requested:

* SPECIFY MIXER SIGNAL LEVEL (dbm)

The user enters P_a and is then asked to enter the values of $R_{j,k}$, one row at a time for $0 \leq j \leq 7$

* ENTER ROW j OF SPUR PRODUCT CONVERSION LOSS MATRIX
* ENTER 9 VALUES (FOR k=0 to k=8)
* ENTER 99 FOR ANY UNKNOWN VALUES
* EXAMPLE: 63., 58., 65., 60., 65., 55., 64., 99, 99

$P_{j,k}$ is computed from $R_{j,k}$ and P_a

The program returns to the beginning of Section 5.3 and the user is again advised that he may enter a new mixer or change data. The user may thus enter as many new mixers as he desires. When he responds no to the question * ENTER NEW MIXER? ANSWER: YES OR NO, the program advances to Section 5.3.2.

5.3.2 Data Correction

The user is asked:

* CHANGE DATA IN CATALOG? ANSWER: YES OR NO

If no the program advances to Section 5.4.

If yes the user may change any or all data relative to any of the mixers. He is asked a sequence of questions to determine the mixer parameters to be changed. For the mixer selected for data correction, he is asked?

* CHANGE CATALOG DESCRIPTOR? ANSWER: YES OR NO
* CHANGE MIXER CONVERSION LOSS? ANSWER: YES OR NO
* CHANGE MIXER SPUR DATA? ANSWER: YES OR NO

The user is then requested to enter the number of the mixer to be corrected:

* ENTER MIXER NUMBER

The sequence of data entry questions of Section 5.3.1, appropriate to the changes requested, are asked of the user to permit data correction.

If the user has responded yes to the question, * CHANGE MIXER SPUR DATA?, he is advised:

* MIXER SPUR CHANGES CAN BE ENTERED FOR SELECTED ROWS

* OF THE MATRIX OR BY CHANGING ALL MATRIX ROWS

* CHANGE SPUR DATA FOR A SELECTED ROW? ANSWER: YES OR NO

If no he is prompted for entry of mixer spur data, one row at a time, as in Section 5.3.1.

If yes he is asked the number of the row selected for data change.

* ENTER ROW NUMBER (J=0 to 7)

The user is then requested to enter the 9 corrected data values for the selected row as in Section 5.3.1. He is then asked:

* CHANGE SPUR DATA FOR ANOTHER SELECTED ROW?

If yes the process is repeated so that all selected rows for any mixer may be corrected.

If no the user is offered an option to correct another mixer by returing to the beginning of Section 5.3.2.

* CHANGE DATA IN CATALOG? ANSWER: YES OR NO

If no the program advances to Section 5.4.

5.4 DATA STORAGE

The data existing in the program work file, whether read from a previously opened data file, or entered in Section 5.3.1, and whether or not corrected in Section 5.3.2, is read into a data file. This data file may be accessed by the mixer catalog computer program for file update and by the signal path and synthesizer computer programs.

It is noted that spur data, whether entered as $P_{j,k}$ or $R_{j,k}$ and P_a is stored in the data file as $P_{j,k}$.

Section VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 ARMM PROGRAM OBJECTIVES

The Advanced Receiver Modeling Methods (ARMM) program is intended to provide aerospace systems engineers with an enhanced capability for determination of receiver performance with respect to parameters significant to airborne systems operation. The enhanced capability derives from the application of the high speed digital computer to tasks related to receiver performance analysis so that they may be effected with minimal effort and with greater speed, accuracy, completeness and flexibility.

6.1.1 Flexibility

The receivers to be modeled for computer determination of performance parameters may differ widely in type (crystal video, T.R.F., superheterodyne), complexity, module types, module interconnection, gain distribution and other module parameter performance. Module parameters may be fixed, variable or programmable. For superheterodyne receivers the local oscillators may be fixed, tuneable or synthesized. Synthesized local oscillators may employ direct, indirect or hybrid synthesis.

The computer programs generated under the ARMM program are required to be sufficiently flexible to accommodate all of the foregoing variations in receiver types, architecture and module performance parameters.

6.1.2 Performance Parameters

The ARMM computer programs are required to compute receiver sensitivity, dynamic range, intermodulation and spurious response performance. The programs are also required to determine the acquisition characteristics of the receiver, including the determination of waveform delay and distortion arising from the transmission of arbitrary signals through the receiver signal path and determination of the time to achieve frequency and phase lock in each phase-locked loop of receiver synthesizers.

6.1.3 User Background

The ARMM computer programs are intended for convenient use by aerospace systems engineers. No background in computer programming, computer design principles or keypunching/computer methods is required to use the programs.

The user will benefit from a strong background in receiver design principles/processes. The user's manual is required to provide the necessary background and derive all algorithms employed in the computer programs.

6.1.4 Program Convenience

The programs should be convenient to use without requiring reference to an extensive list of instructions for program operation and data entry. Accordingly the computer programs should be interactive, suitable for use at a computer terminal. The user need only select from options offered by the programs and enter data in accordance with self-explanatory instructions. All data entry and user responses should be unformatted.

The program should not bomb for want of any requested data; a default computation should provide maximum useful output with the available data.

The computer programs should offer convenient data display, edit, store and recall capability.

6.2 ARMM PROGRAM OUTPUT

All of the objectives listed in Section 6.1 have been achieved. Two computer programs have been developed that model the receiver signal path and receiver synthesizer. The program output is described in this section.

6.2.1 Signal Path Program (RXSG)

The program models the following module types:

- Linear (fixed, variable)
- Filter (fixed, tuneable)
- Mixer
- Amplifier
- Detector
- Combiner

The program computes the following performance parameters:

- Sensitivity
- Dynamic Range
- Intermodulation
- Spurious Responses (Frequency and Level)
- Signal Waveforms

Worst case conditions are determined for each spur product type generated at each mixer. Worst case spurious response levels are computed. Algorithms have been derived to determine receiver performance for the parameters indicated for any arbitrary sequence of modules listed above. The maximum number of modules that may be employed per receiver is limited by storage capacity requirements to 32, including 7 filters and 5 mixers.

6.2.2 Synthesizer Program (SYN)

The program models the following module types encountered in interconnected phase locked loops:

- VCO
- Mixer
- Frequency Divider/Multiplier (fixed/programmable)
- Phase Comparator
- Filter

The program computes the following performance parameters:

Spurious phase modulation on each loop output signal
Noise phase modulation on each loop output signal
Acquisition characteristic for each loop

Worst case programmable element values are determined for each spur product type generated at each mixer and worst case spurious phase modulation is computed. The effect of variation of programmable elements on spurious and noise phase modulation on each loop output signal and on the acquisition characteristics for each loop is computed.

Algorithms have been derived to determine synthesizer performance with arbitrary interconnection of multiple phase locked loops. The program accommodates 12 loops, 12 mixers, 12 programmable elements and 2 reference sources.

6.2.3 Auxiliary Mixer Program (SPURS)

An auxiliary program has been developed to generate a file containing the performance data for a catalog of mixers. The data is called by the signal path and synthesizer programs.

6.2.4 User's Manual

The user's manual provides a sequence of operating instructions for each computer program, derives all algorithms forming the basis for the performance computations and provides a tutorial exposition of the receiver processes that are employed in the signal path and synthesizer.

6.3 ARMM PROGRAM BENEFITS

Receiver performance computation for each of the performance parameters is dependent on the parameters of many, if not all, modules in the signal path and/or synthesizer. Although the algorithms that determine the contribution of each module to the performance of the receiver for each parameter are not mathematically complex, their number and interaction require an extensive set of computations for receivers of even moderate complexity. The ARMM computer program employs the high speed digital computer to organize and perform these computations to provide the basis for an advanced methodology for evaluation of receiver performance in great detail.

When the computer is not applied to the computation of receiver performance the required calculations are sufficiently extensive so that significant performance parameters, deriveable from available module data, are often ignored during the engineering phase of receiver development programs, resulting in failure to achieve specification compliance.

The primary benefits obtained with the ARMM computer programs derive from the enhanced detailed knowledge of receiver performance provided to receiver users and designers, together with information relative to the contribution of each module to overall performance for each parameter. It is reasonable to expect that wide use of the programs would result in improved receiver designs due to:

- o enhanced compliance with specifications.
  Areas of non-compliance due to obscure causes will be found prior to finalization of the receiver design.
- o minimization of required test time.
  The emphasis given to determination of worst case conditions permits rapid verification of performance compliance.
- o improved proposal evaluation.
  ARMM computer program flexibility permits comparison of performance of proposals that differ widely in design approach. With little effort the proposal evaluator determines that the proposed design is sufficiently complete to assure specification compliance.
- o improved integrated system performance.
  Detailed knowledge of receiver spurious response and intermodulation performance leads to enhanced accuracy in system electromagnetic compatability predictions. ARMM receiver acquisition time and waveform analysis computations lead to accurate determination of the reaction time of the integrated system. Sensitivity and dynamic range computations permit determination of system maximum and minimum operating range.
- o improved technical monitoring.
  During the receiver engineering phase, usually of extended duration, the only technical output is module performance data. ARMM permits determination of suitability of module performance.
- o upgraded receiver vendors.
  Detailed knowledge of receiver performance and its relation to module parameters should result in improved receiver designs in compliance with specifications. Improved capability for interim technical monitoring and ability to assess the impact of any variation of module parameters should enhance compliance with schedules and design-to-cost engineering.

6.4 FUTURE COMPUTER PROGRAM ENHANCEMENTS/RECOMMENDATIONS

The ARMM computer programs may be used to model, directly or indirectly, almost all receiver modules, in accordance with the parameters that characterize the library of module types. Nevertheless, several areas of enhancement of the computer programs and the user's manual, will permit a more accurate modeling of some receiver types. These areas of enhancement are discussed in this section.

- o Receiver design trends lead toward the use of both analog and digital filters. Hence, the library of module types should be extended to include digital filters.

- o The filter types modeled are based upon the use of lumped components leading to network functions represented as the ratio of two polynomials in S with real coefficients having poles in the left half S plane. Filters are often designed as a sequence of coupled resonators modeled by distributed parameters. The programs should be extended to model such filters.

- Narrow band pass filters result in network function polynomials that are ill conditioned so that the most common root finding computer algorithms do not converge. An improved root finding algorithm should be generated for use with the ARMM program. This will avoid the need for an off-line auxiliary program.

- The ARMM programs are well suited to determine signal, noise, distortion and interference levels appearing at the detector input. The detector models are idealized. An auxiliary computer program can be written to model a number of the more common conventional and synchronous detector types and compute detector output characteristics, threshold, and, in the case of synchronous detectors, the signal acquisition characteristic.

- The user's manual may be expanded to include an appendix on flow graph theory to assist in the indirect modeling of receivers with r. f. feedback. Additional examples could be included to illustrate other methods for indirect modeling of receivers by the ARMM computer programs.

Section VII

GLOSSARY

Term	Unit	Definition
Acquisition Characteristic	n/a	Time history of phase and frequency errors on the phase locked loop output signals of a synthesizer.
Amplifier	n/a	Module type generating intermodulation products characterized by its available power gain, and a noise figure generally greater than one. The desired output is at the same frequency as the input signal.
Amplitude Modulation Function	volt	See Carrier, Modulated
Amplitude Modulation Index	-	See Carrier, Modulated
Available Power	watt	The maximum power obtainable from a source or network by means of a choice of terminating impedance.
Available Power Gain		See Gain, Available Power
Carrier	n/a	The signal $r_o.\cos(\omega_o t+\phi_o)$ where ω_o, r_o and ϕ_o are constant.
Carrier, Modulated	n/a	The signal $r(t)\ \cos(\omega_o t+\phi(t))$ where $r(t)$ and/or $\phi(t)$ are time functions dependent on a modulating signal, $m(t)$. $r(t)$ is the amplitude modulation function. $r(t)=1+K_A m(t)$; K_A=amplitude modulation index. $\phi(t)$ is the phase modulation function. $\phi(t)=\phi_D m(t)$ for PM. $\phi(t)=\omega_D\int_o^t m(t)dt$ for FM ϕ_D and ω_D are peak phase and frequency deviation.
Columns, One and Two	n/a	Performance computations made with two sets of programmable elements representing the extremes of performance relative to synthesizer output frequencies.
Combiner	n/a	Module type with multiple inputs providing a single output signal given by the superposition of the input signals.
Conversion Loss		See Mixer Conversion Loss

Term	Unit	Definition
Crossover Spur	n/a	Mixer spur product which has the same frequency as the desired mixer output for a possible pair of mixer input signal frequencies.
Crossover Spur Frequency	MHZ	The set of loop output frequencies which result in a mixer crossover spur.
Crystal Video Receiver		See Receiver, Crystal Video
Detector	n/a	Module type that returns the modulating signal when a modulated carrier is applied to its input.
Detector, AM Envelope	n/a	Module type that returns r(t) when fed with modulated carrier $r(t)\cos(\omega_o t+\phi(t))$.
Detector, AM Square Law	n/a	Module type that returns $r^2/2$ when fed with modulated carrier $r(t)\cos(\omega_o t+\phi(t))$.
Detector, FM	n/a	Module type that returns $d\phi/dt$ when fed with modulated carrier $r(t)\cos(\omega_o t+\phi(t))$.
Detector, PM	n/a	Module type that returns $\phi(t)$ when fed with modulated carrier $r(t)\cos(\omega_o t+\phi(t))$.
Dynamic Range	db	Difference (in decibels) between 1db compression signal level and minimum signal level.
Envelope Detector		See Detector, AM Envelope
Feedback Input Matrix	n/a	An array with rows associated with the phases of the feedback signals to the loop phase comparators in a synthesizer and with columns associated with the adjoined vector of the phases of the VCO and mixer outputs.
Filter	n/a	Module type characterized by a gain constant and the location of poles and zeros.
Filter, Baseband	n/a	See Filter, Post Detection
Filter, Fixed	n/a	Filter with constant parameters.
Filter Gain Constant	*	The coefficient of the highest degree term of the filter network numerator polynomial.

*$(rad/sec)^{d-n}$ (n and d are degrees of numerator and denominator polynomials).

GLOSSARY (Cont'd)

Term	Unit	Definition
Filter Input Impedance	ohm	Impedance looking into the input terminals of a network with the load impedance connected to the network output terminals.
Filter Output Impedance	ohm	Impedance looking into the unloaded output terminals of a network with the input signal source impedance connected to the network input terminals.
Filter Poles	rad/sec	The complex roots of the filter network numerator polynomial.
Filter, Post Detection	n/a	Filter located in that part of the receiver after the detector.
Filter, Predetection	n/a	Filter located in that part of the receiver before the detector.
Filter Transfer Function	-	Network open circuit voltage gain. (Open circuit network output voltage divided by open circuit input voltage.) Given as a ratio of two polynomials in the complex frequency variable S.
Filter, Tuneable	n/a	Filter with parameters that vary with receiver tuned frequency.
Filter Zeros	rad/sec	The complex roots of the filter network denominator polynomial.
Frequency, Deviation	rad/sec	See Carrier, Modulated
Frequency Error	MHZ	The difference between the frequency of the loop output at any time and its steady state output frequency.
Frequency Plan	n/a	The set of operating frequencies at each VCO, phase comparator reference and mixer inputs and output.
Frequency Standard	n/a	See Standard, Frequency
Gain		See Gain, Available Power
Gain, (Available Power)	db	The ratio of available power at the network output to the available power in the source driving the network (expressed in decibels)

GLOSSARY (Cont'd)

Term	Unit	Definition
Input Impedance		See Filter Input Impedance.
Intermodulation Intercept (Second Order, Third Order)	dbm	Level of two sinusoid input signals corresponding to the intersection of the signal and (second order, third order) output vs input signal level characteristics.
Intermodulation Performance (Second Order, Third Order)	dbm	Permissible level of two sinusoid input signals that produce a (second order, third order) intermodulation product at a level equal to the noise level.
Inversion, Mixer	n/a	Mixer process occurring when output signal decreases in frequency when input signal increases in frequency.
Linear	n/a	Module type contributing no intermodulation; transfer function H(S) independent of S.
Mixer	n/a	Module type with two inputs (signal and local oscillator) and a desired output at a frequency equal to the sum or difference of their frequencies.
Mixer Catalog	n/a	A list of mixers with tabulated parameters.
Mixer Catalog Descriptor	n/a	A three word listing in the mixer catalog: (1) manufactuer, (2) manufactuer's part or catalog number, (3) local oscillator power level.
Mixer Conversion Loss	db	The negative of the mixer available signal power gain.
Mixer Inversion		See Inversion, Mixer
Mixer Output Matrix	n/a	An array with rows associated with the output phases of the mixers in a synthesizer and with columns associated with the adjoined vector of the phases of the reference standards, VCO's and mixer outputs.
Mixer Spur Product		See Spur Product
Modulated Carrier	n/a	See Carrier, Modulated

Term	Unit	Definition
Noise Bandwidth	HZ	For a network with transfer function H(S), with frequency of maximum transmission $\omega_o/2\pi$, the noise bandwidth is $(\int_o^\infty \lvert H(j\omega)\rvert^2 d\omega/2\pi)/\lvert H(j\omega_o)\rvert^2$
Noise Figure	db	Ratio of input to output signal/noise (expressed in decibels).
Noise Power Level	watt/ HZ	The available noise power from a source or network in a unit bandwidth at a prescribed frequency.
Noise Power Spectral Density	watt/ HZ	The available noise power from a source or network in a unit bandwidth at a prescribed positive or negative frequency (one half of the noise power level).
Noise Spectral Density	$volt^2$/ HZ	Mean squared noise voltage from a source or network in a unit bandwidth at a prescribed positive or negative frequency.
1db Compression Level	db	The input signal level to a module at which its gain is 1db less than the gain for small signal levels (indicating a condition of near overload).
Output Impedance		See Filter Output Impedance
Phase Comparator	n/a	A module with two inputs (reference input signal and feedback input signal) that returns and output that is a function of the phase difference of the input signals.
Phase Comparator Bias	db	The ratio of the phase comparator output signal with zero phase difference between input signals to the phase comparator gain constant, expressed in decibels.
Phase Comparator Gain Constant	volt/ rad	The peak slope of the output signal voltage vs input phase difference characteristic.
Phase Comparator Reference Leakage	db	The ratio of the undesired phase comparator output signal at reference frequency to the phase comparator gain constant, expressed in decibels.

GLOSSARY (Cont'd)

Term	Unit	Definition
Phase Deviation	rad	See Carrier, Modulated
Phase Error		The difference between the loop output phase and the reference phase.
Phase Locked Loop	n/a	A set of interconnected modules in a negative feedback configuration that controls the phase of an output signal relative to a rational fraction of the phase of a reference signal.
Phase Modulation Function	rad	See Carrier, Modulated
Phase Modulation, Noise	rad	Phase modulation on a phase locked loop output signal caused by noise generated in the loop or in another loop.
Phase Modulation, Spurious	rad	Peak phase deviation on a phase locked loop output signal caused by a spurious signal generated in the loop or in another loop.
Phase Noise Spectral Density	rad^2/HZ	Mean squared phase deviation in a unit bandwidth on a phase locked loop output signal caused by noise at a prescribed positive or negative frequency generated in the loop or another loop.
Phase Noise Spectral Density, VCO	rad^2/HZ	Mean squared phase deviation in a unit bandwidth of a VCO output signal caused by VCO noise at a prescribed positive or negative frequency.
Programmable Matrix Element	n/a	The elements of the mixer output, reference input and feedback input matrices that vary with synthesizer output frequency. The variations correspond to programmable values of frequency multiplier and/or divider ratios.
Poles		See Filter Poles
Receiver, Crystal Video	n/a	A receiver divided into two sections by the detector: (a) a predetection section (without amplification), (b) a post detection (or baseband) section. The signal has a common frequency throughout the predetection section.

GLOSSARY (Cont'd)

Term	Unit	Definition
Receiver, Superheterodyne	n/a	A receiver divided into two sections by the detector: (a) a predetection section (with amplification). (b) a post detection (or baseband) section. The predetection section is divided into two subsections by the first mixer: (a) the receiver front end (those blocks from the input through the first mixer). (b) the intermediate frequency subsection (those blocks between the first mixer and the detector). The signal changes frequency at each mixer.
Receiver, Tuned Radio Frequency	n/a	A receiver divided into two sections by the detector: (a) a predetection section (with at least 1 amplifier), (b) a post detection (or baseband) section. The signal has a common frequency throughout the predetection section.
Reference Input Matrix	n/a	An array with rows associated with the phases of the reference signals to the loop phase comparators in a synthesizer and with columns associated with the adjoined vector of the phases of the reference standards, VCO's and mixer outputs.
Reference Phase	rad	The frequency of the steady state output signal in each loop is a rational fraction of the standard frequency. The reference phase at each loop output is the instantaneous phase of the standard signal multiplied by the rational fraction.
Sensitivity	dbm	The signal level yielding a prescribed signal/noise ratio.
Signal Voltage	volt	The open circuited source voltage of the input or output signal of a network.
Spur product (j,k)	n/a	Undesired mixer output at frequency $\lvert j*\text{signal freq} \pm k*\text{osc freq}\rvert$
Spur Product (j,k) Conversion Loss	db	The difference (in decibels) between the desired signal output level and the spur product (j,k) level for a prescribed value of the signal input level.

GLOSSARY (Cont'd)

Term	Unit	Definition
Spur Product Conversion Loss Table	n/a	A table of spur product conversion losses (Table 1).
Spur Product (j,k) Intercept	dbm	For $j \neq 1$, the mixer input signal level at which the j,k spur product output characteristic intersects the desired signal output characteristic.
Spur Product Intercept Table	n/a	A table of spur product intercepts (Table 0).
Square Law Detector		See Detector, AM Square Law
Standard, Frequency	n/a	A signal source that serves as a frequency reference for the output signals from a frequency synthesizer.
Superheterodyne Receiver		See Receiver, Superheterodyne
Synthesizer	n/a	A device consisting of interconnected phase locked loops, generating one or more output signals with frequencies that are rational fractions of the frequency of a reference standard.
Transfer Function		See Filter Transfer Function
Tuneable Filter	n/a	See Filter, Tuneable
TRF Receiver		See Receiver, Tuned Radio Frequency
VCO	n/a	A signal source module with output frequency functionally dependent on its input signal voltage.
VCO Gain Constant	MHZ/volt	The slope of the VCO frequency vs tuning voltage characteristic at any operating frequency.
VCO Noise Spectral Density		See Phase Noise Spectral Density, VCO

GLOSSARY (Cont'd)

Term	Unit	Definition
Voltage Contolled Oscillator		See VCO
Worst Case Frequency	MHZ	For any spur type, the set of loop output frequencies which result in minimum filtering to the synthesizer outputs.
Zeros		See Filter Zeros

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